INTERPRETATIONS OF RESULTS FROM HYDRAULIC MODELING OF THERMAL OUTFALL DIFFUSERS FOR THE SAN ONOFRE NUCLEAR POWER PLANT

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INTERPRETATIONS OF RESULTS

FROM

HYDRAULIC MODELING OF THERMAL

OUTFALL DIFFUSERS

FOR THE

SAN ONOFRE NUCLEAR POWER PLANT

submitted to

Southern California Edison Company

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

1. INTRODUCTION

This report presents an interpretation of results obtained during the hydraulic model study previously documented in "Hydraulic Modeling of Thermal Outfall Diffusers for the San Onofre Nuclear Power Plant" (1)* which described the hydraulic laboratory studies conducted to investigate outfall configurations for the thermal discharge from proposed Units 2 and 3 at the San Onofre Nuclear Generating Station, jointly owned by the Southern California Edison Company and San Diego Gas and Electric Company.

A number of different experimental investigations were performed to develop the conceptual design for the new Units 2 and 3 discharge diffusers. The primary reason for the investigations was the new California thermal standards (2)(essentially ambient temperature increment less than 4°F),which in effect precluded the use of shoreline or single outlet discharges for new units and necessitated the use of multiport diffusers.

The result of the investigations of different diffuser concepts was the establishment of a preliminary design for the discharge structures for Units 2 and 3, each consisting of a diffuser 2500 ft long containing 76 discharge nozzles with a nominal discharge velocity of 13 ft/sec. This preliminary design was later modified somewhat by the engineers of the Southern California Edison Company (SCE) in consideration of other factors such as structural requirements, cost, construction problems, and more accurate bathymetric details at the site. As a result the final design for each diffuser contains 63 discharge ports of diameters varying from 21.85 to 23.9 inches. The

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* Numbers refer to references.

discharge ports are nozzle-riser assemblies at alternate angles of ±25° with respect to the longitudinal axis of the diffuser and 20° up from horizontal. The nozzles are positioned approximately 6 ft from the ocean bottom. The diffusers are aligned perpendicular to shore and extend from approximately 3500 ft to 8500 ft offshore.

The performance of the final diffuser design was evaluated in a series of confirming tests (see (1)). The major results will be summarized and discussed in section 3 of this report.

Sections 3 and 4 will also include projections and elaborations on several aspects of the diffuser performance to be expected in the prototype. The possible interactions of the proposed diffuser operation with existing site factors such as ocean currents, water temperature, heat losses, and the existing power plant (Unit 1) will also be discussed in section 4.

2. DESIGN EVALUATION PHILOSOPHY

2.1 Thermal Discharge Standards

The recommended design was an outcome of complying with the California thermal standards* for coastal water. These standards relate to three zones:

1. the shoreline
2. the substrate
3. the ocean surface beyond 1000 feet from any point of the diffusion structure.

For these zones, any rise of water temperature of more than 4°F above natural temperature is prohibited. The surface temperature limitations must be maintained at least 50% of the duration of any complete tidal cycle. This means that design for compliance must be based on the most adverse day of the year.

The standards prescribed do not explain how "natural temperature" is to be measured and, as will be discussed subsequently, the characterization of the temperature at a particular point in the ocean is far from straightforward.

It will be shown later in this report that the natural temporal and areal fluctuations in the instantaneously measured temperature of the Southern California Bight exceed the prescribed temperature limits imposed by these regulations. It will also be shown that a determination of whether a discharger is in violation or compliance can only be made statistically if at all.

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*Ref. (2).

Since ΔT values follow a frequency distribution, the definition of ΔT in the regulations is as important as the numerical value. The California standards were believed to be as stringent as any that would be imposed on extreme values, especially considering that as a practical matter the temperature changes induced by the outfalls will be shown to be often smaller than natural fluctuations at the site.

2.2 Design Philosophy

The design of the diffusion structures was developed to obtain compliance with the California thermal standards, based essentially on the worst day of the year.

The most efficient way to achieve $\Delta T < 4°F$ at 1000 feet from the outfall is by initial mixing of the condenser discharge water with seawater by means of a diffusion structure. Even if surface cooling exists it may be shown that the rate of cooling is so slow as to be negligible for purposes of meeting requirements. At the very minimum each part of condenser discharge must be mixed with 4 parts of seawater at "natural temperature". To be prudent the predicted dilution should exceed this by some margin, i.e. a minimum acceptable dilution must be established (see below).

Protection of the shoreline will be obtained by aiming the diffuser discharge jets offshore to produce a general offshore drift superimposed on any longshore currents. The induced offshore drift will also provide greater protection against possible reentrainment of previously discharged warm water into the plume.

The substrate will be protected by achieving stratified flow after initial mixing of the discharge with the ambient water. The diluted warm water will then drift away from the site in a surface layer thereby permitting cool new diluting water to circulate under the warmed surface layer. Contact of warmed water with the bottom is thus avoided.

The requirements outlined above indicated that an outfall diffuser comprising a length of discharge conduit containing discharge jets angled offshore would provide the essential features required. Refinements of the design included:

i) Alternating consecutive discharge ports to each side of the diffuser to provide a maximum path length for entrainment of cool ambient bottom water without interference between jets. 25° was selected as being an appropriate compromise between reduction in offshore momentum and maximum path length.

ii) Angling the discharge jets 20° up from horizontal to maximize horizontal momentum and buoyant jet path length but also to guarantee that the bottom would a) remain untouched by a ΔT contour exceeding 4°F and, b) not be scoured by the discharge jet.

iii) Placement of the diffuser in sufficient depth of water to guarantee an adequate supply of diluting water. If this were not the case, and the diffuser jets required more diluting water than could be provided by the inflow of new water, reentrainment of the discharge would occur with a reduction in net dilution.

3. HYDRAULIC MODEL TESTS

3.1 Laboratory Target Value of ΔT

Prior to embarking on systematic laboratory tests of the preliminary diffuser designs it was decided to establish a target value of ΔT for use in these tests. A substantial number of unknown parameters are involved in the hydraulic modeling process and it was considered imprudent to design a diffuser system that would only just attain $\Delta T < 4°F$ in the model without allowing some margin for error in the scaling from model to prototype.

A careful and critical assessment of the various unknown factors was therefore made to establish a laboratory value of ΔT that would guarantee that the prototype performance would be satisfactory with a high degree of assurance.

For the hydraulic models in the 20 x 36 ft basin, a target value of 2.5°F was established, in order to allow a margin of 1.5°F for model-prototype differences. The detailed breakdown, based on the writers' judgment, was as follows:

(1). Target value of ΔT selected as laboratory criterion — 2.5°F

(2). Model-prototype differences

a. Possible direct error in model-prototype behavior due to fluid effects which are impossible to model exactly (friction on the ocean bottom, interfacial friction between warm and cool layers, Reynolds number effect on initial jets, distortion of scales, ocean turbulence):

±25% x 2.5° — 0.6°

b. Effects which are not modeled. Allowance is made for only one of the following effects at any one time: 0.6°

(i) Onshore currents (with jets aimed offshore, an onshore current resisting the offshore jetting could cause some "piling up" of warm water and reduce the initial dilution).
Estimated: 0.5°F

OR

(ii) Increase of background temperature by Unit 1 discharge, when the plume of Unit 1 is carried over Units 2 or 3.
Estimated: 0.6°F

OR

(iii) Unknown prototype current patterns which may have complex adverse effects when all spatial and temporal correlations are considered (including recirculation of warm water through the intakes, and recirculation of an old thermal field over the outfall one or more times).
Estimated: 0.5°F

Subtotal	3.7°

(3.) Final margin of safety covering all other factors, (such as slight errors in prediction of condenser flows and temperature; as-built depths departing slightly from design depths for ports, and any unanticipated sources of error)

±8% x 3.7°	0.3°
TOTAL	4.0°F

The above estimates were based on the best judgments that could be made before any laboratory tests were carried out. As will be described subsequently, much of the laboratory testing program was to obtain better estimates of many of these factors

* Note the events are not necessarily mutually exclusive. The 0.6° could arrive from a combination of events.

by determining the sensitivity of the results to changes in the factors.

A summary of the laboratory tests performed and the results obtained follows.

3.2 Hydraulic Model Test Results

An extensive series of hydraulic model tests of preliminary diffuser designs was carried out. The purpose of these systematic tests was to determine the sensitivity of the predicted dilutions to various design and modeling variables and thereby establish, in a quantitative way, the functional relationships between these variables and diffuser performance. The dynamic similitude basis of the hydraulic modeling process will not be considered here, nor will the experimental facility be described. These are fully documented in the Caltech W. M. Keck Laboratory Report, KH-R-30 (1). However, a summary of the test results obtained will be presented in order to show the range of results obtained and the influence of various design and modeling parameters. Preliminary tests were conducted for four new units even though only two are planned for construction.

The hydraulic model studies related to the design of the Units 2 and 3 diffusers can be divided essentially into three categories*:

1) A series of experiments to test the effects of design variables such as diffuser and jet alignment, diffuser length and depth, ocean currents, and the discharge temperature.

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* Model tests were also conducted for Unit 1, the Units 2 and 3 intakes during heat treatment, and the hydraulic performance of the discharge nozzles. These will not be described here. They are summarized in Ref. (1).

2) A series of experiments to test the modeling procedures by varying modeling parameters such as scales and distortion ratios.
3) Confirming tests based on the actual diffuser design and using detailed site bathymetry.

For completeness the test results obtained and the conclusions indicated by each of these tests will be summarized. It is believed that an understanding of the results of all these tests is of substantial importance in the assessment of how the diffuser systems will perform in prototype operation. The effects of each variable will be considered in turn:

(i) Diffuser orientation

One set of preliminary tests was to consider the effect of diffusers parallel to shore but with the discharge jets aimed offshore (perpendicular to the diffuser axis). Figures 3.1, 3.2 and 3.3 show the effect of such a set of diffusers for four possible units at San Onofre (Units 2, 3, 4, 5); the discharge of Unit 1 is also included. The results of these tests indicated that at the proposed location of the diffusers, in 52 feet of water, the amount of diluting water required by the diffuser jets was such as to intercept almost any ocean current moving between the diffusers and the shore. The net effect was therefore to induce a possible stagnation zone and possible recirculation downstream of the diffusers. For this reason this preliminary design was rejected as being impractical for the San Onofre site.

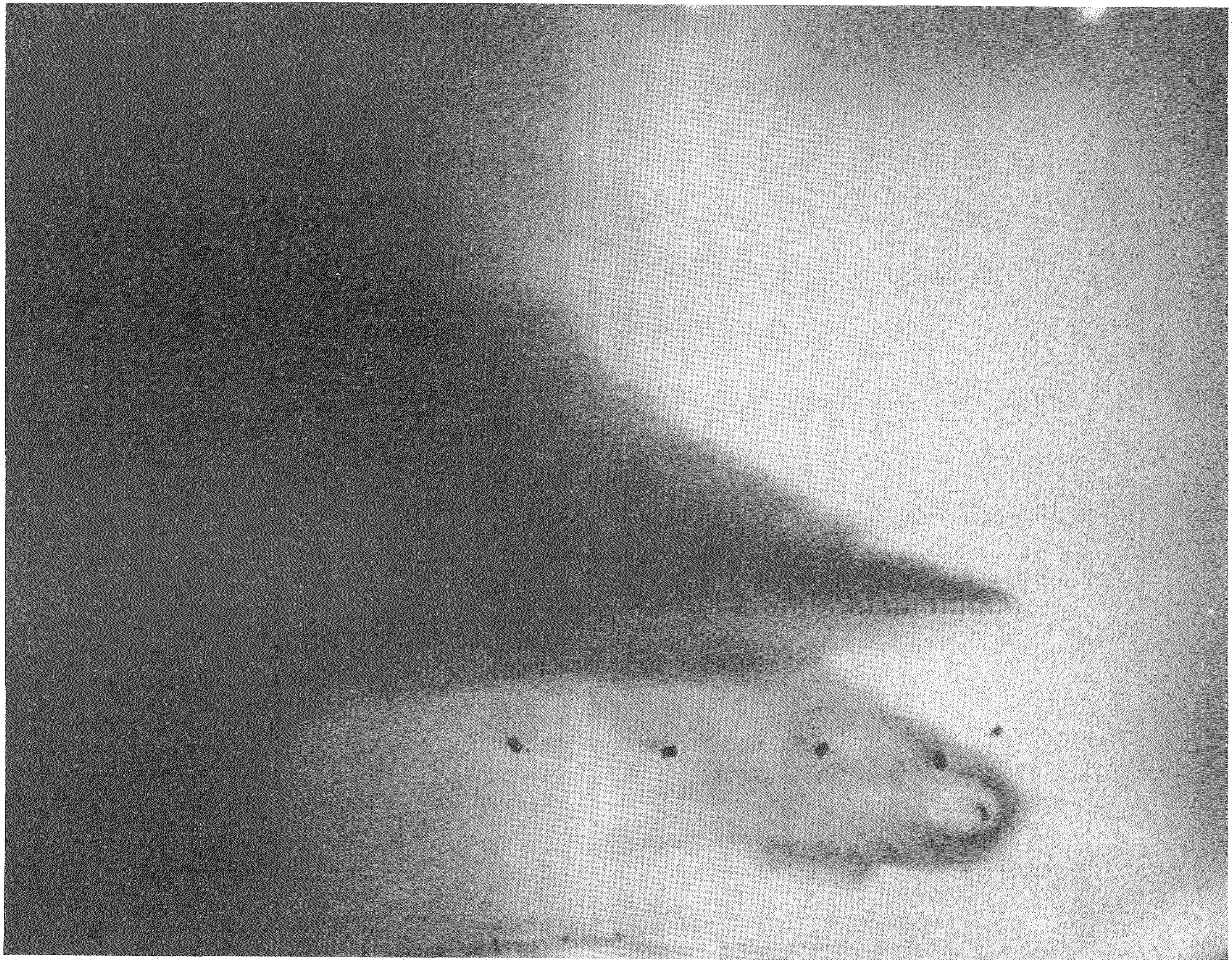

Figure 3.1 Offshore discharge of heated effluent into a current of 0.5 knot (diffusers parallel to shore).

Figure 3.2 Offshore discharge of heated effluent into a current of 0.15 knot (diffusers parallel to shore).

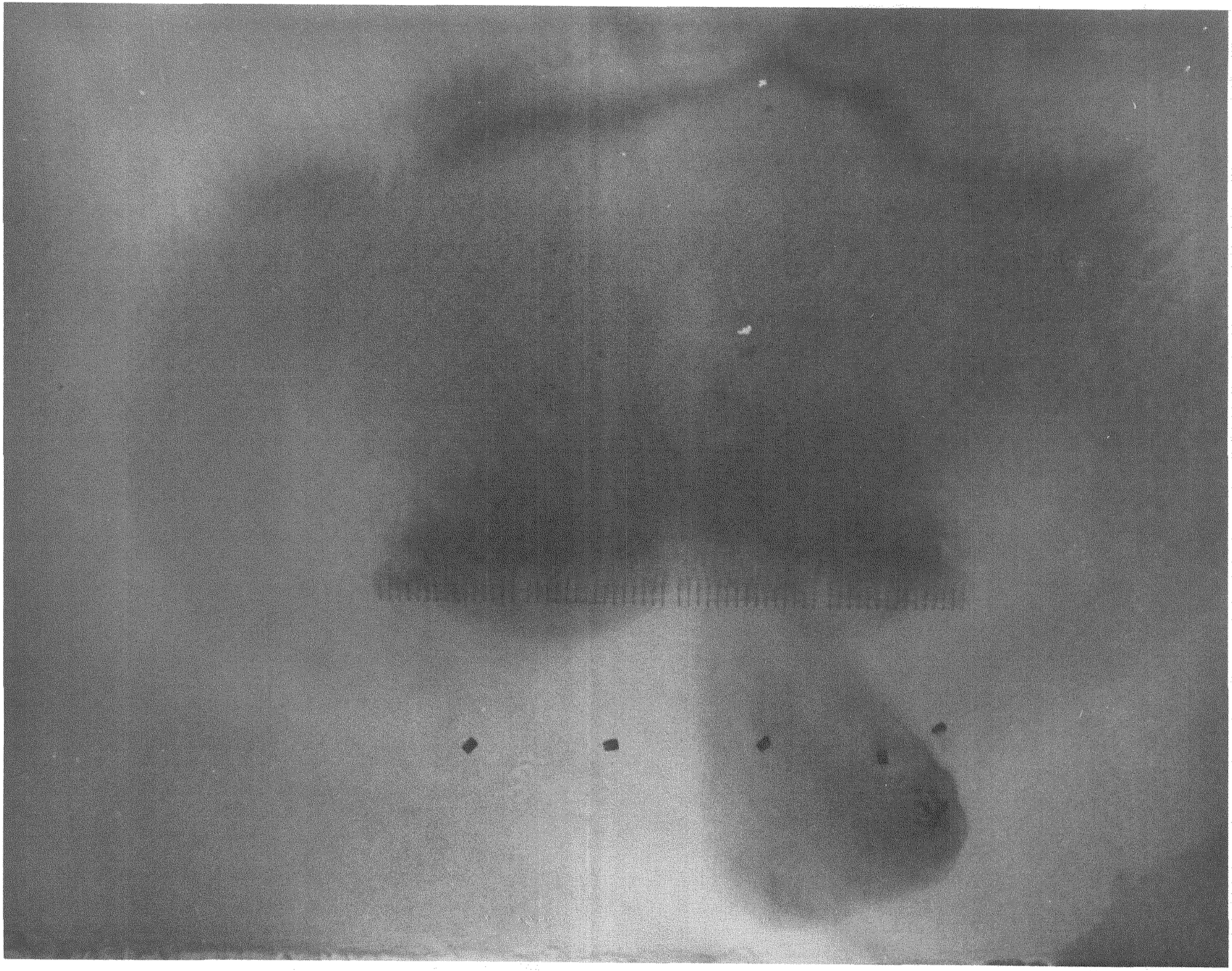

Figure 3.3 Offshore discharge of heated effluent with no ambient current (diffusers parallel to shore).

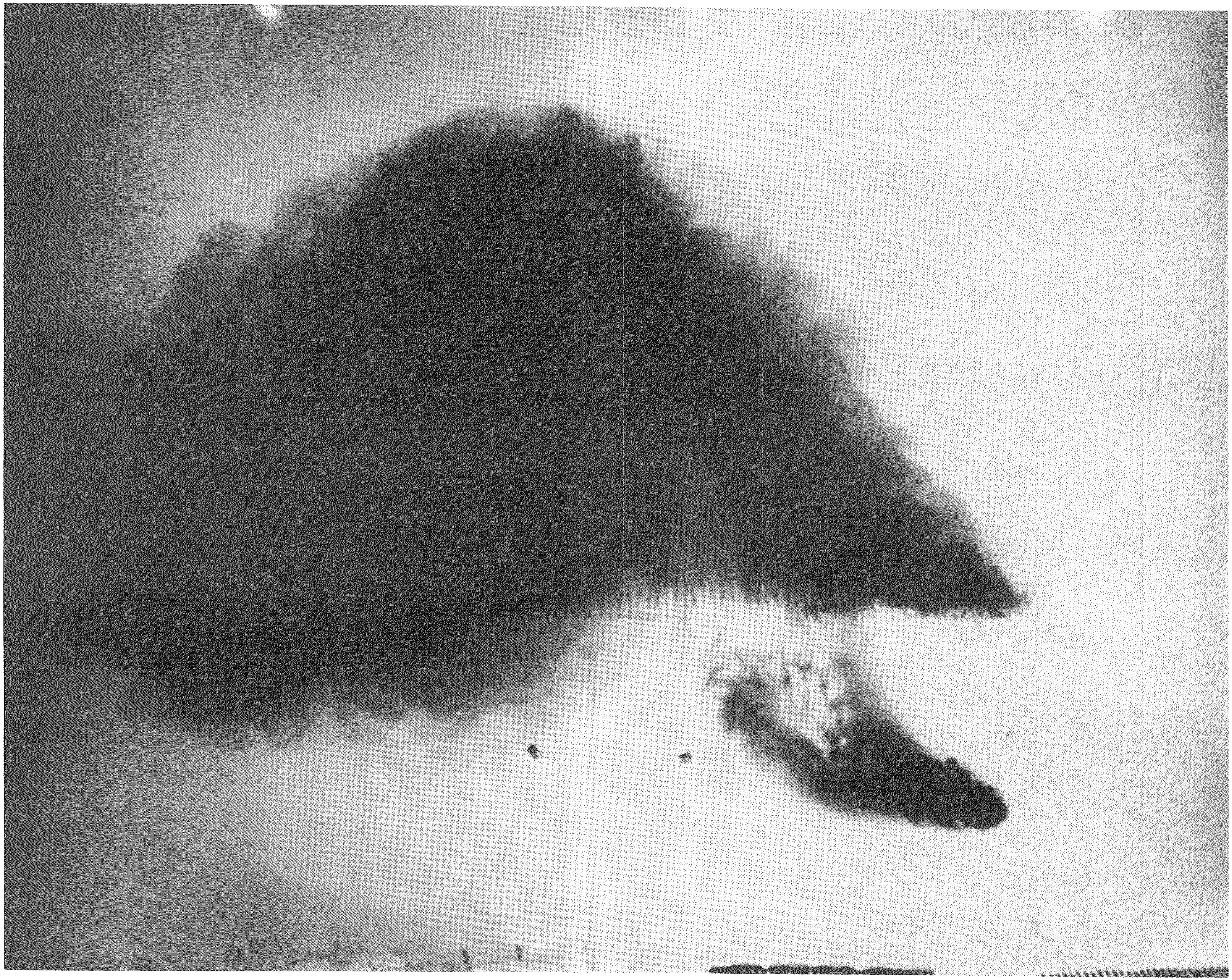

Figure 3.4 Offshore discharge of <u>unheated</u> effluent into an ambient current of 0.15 knot (diffusers parallel to shore).

Further preliminary tests with the diffusers perpendicular to shore and with the jets still directed offshore, but angled at ±20° to the diffuser axis, indicated that the problems of stagnation experienced with the parallel to shore diffusers was in essence solved. The reason for this is that the diffuser entrainment flow was then provided mostly by the flow intercepted by the diffusers rather than by the flow between the diffusers and the shore.

(ii) <u>Discharge temperature</u>

One of the tests done with the diffusers parallel to shore was with a zero temperature difference between the discharge and the ambient fluid but otherwise for the same conditions as in Figure 3.2. The result (Figure 3.4) was dramatically different. Instead of the stratified flow system developing as shown in Figures 3.1, 3.2, and 3.3, the flow was now vertically well mixed since the diffuser jets no longer had any buoyancy. The net effect was that an intense recirculating eddy developed wherein the discharge was reentrained into the diffuser jets. It was apparent that the effect of the discharge buoyancy was to produce a stratified flow in which the warmed water traveled on the surface thereby permitting the cool entrainment flow to pass beneath.

(iii) <u>Diffuser length and depth</u>

The series of tests on diffuser orientation led to the conclusion to proceed with an investigation of diffusers perpendicular to shore and to evaluate the effect of diffuser lengths and water depth.

Two sets of four diffusers were tested:

a) a set of shorter diffusers (2000 ft long) located at a depth range of 30 to 50 ft.

b) a set of longer diffusers (2500 ft and 3000 ft long) located at a depth range of 40 to 67 ft.

The layout for the 2000 ft diffusers is shown in Figure 3.5 and the results obtained in Figure 3.6. For the 2500 ft and 3000 ft diffusers the layout is shown in Figure 3.7 and the results in Figure 3.8. The main conclusion drawn from these results was that the shorter diffusers would not meet the laboratory target value of $\Delta T/\Delta T_o^* \leq 12.5\%$ but that the longer set would. It was also apparent that the Unit 1 plume would have a significant effect on the results obtained.

The outcome of the above tests was a systematic evaluation of the diffuser-length-depth dependence for Units 2 and 3 by using the configurations

1. 2000 ft for Unit 2, 2500 ft for Unit 3
2. 2500 ft for Unit 2, 2500 ft for Unit 3
3. 2500 ft for Unit 2, 3000 ft for Unit 3

and locating the diffusers at simulated depths given as follows:

Designation	Prototype depth (ft) at end nearest shore	Approximate distance offshore (ft) to first nozzle
N ("near")	30	3500
NM	35	4500
M (medium)	40	5500
F ("far")	50	7500

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* ΔT_o is the temperature increment in the effluent, assumed 20°F; the target value temperature increment ΔT was selected as 2.5°F.

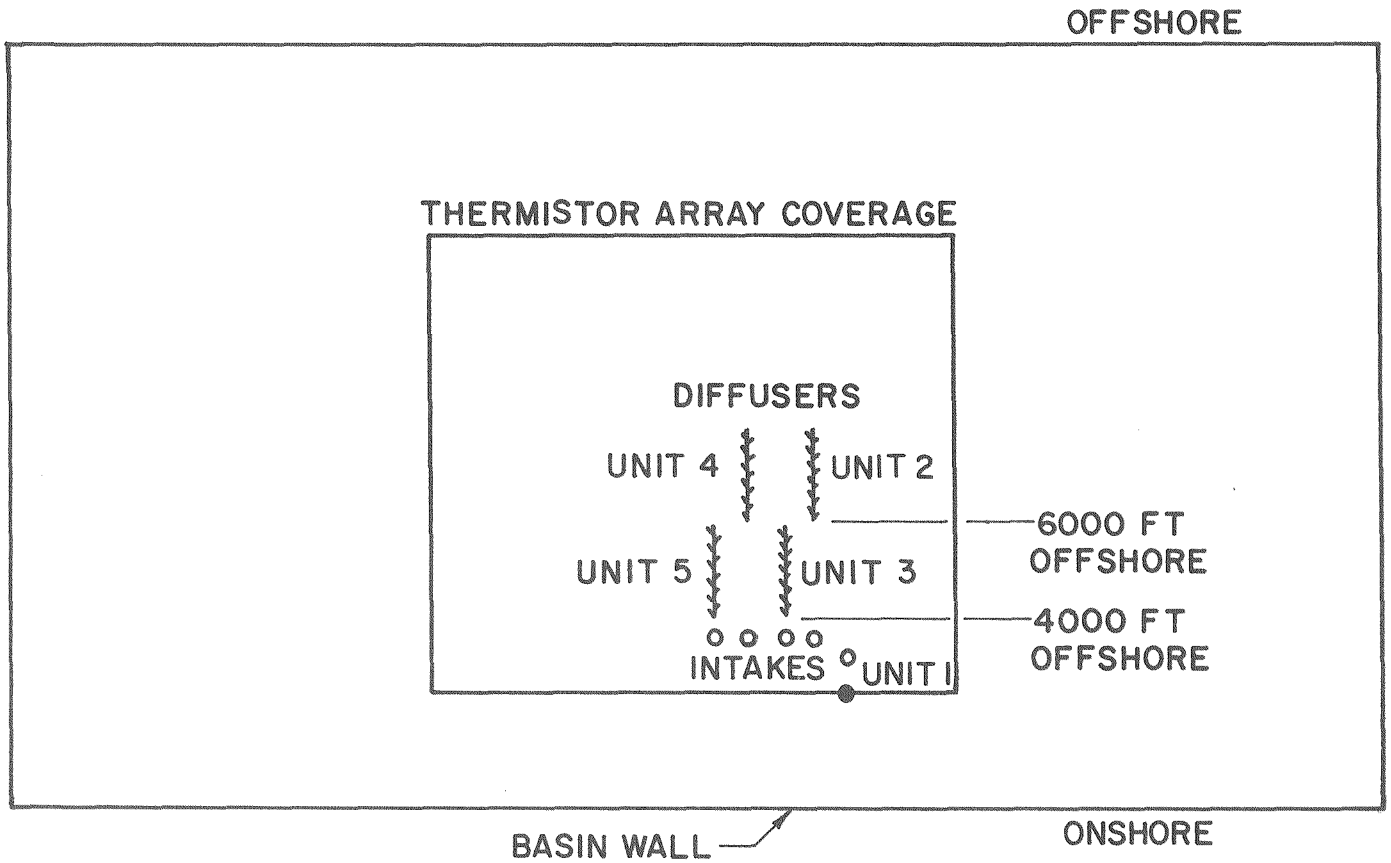


Figure 3.5 Schematic of basin layout for first set of perpendicular-to-shore diffusers.

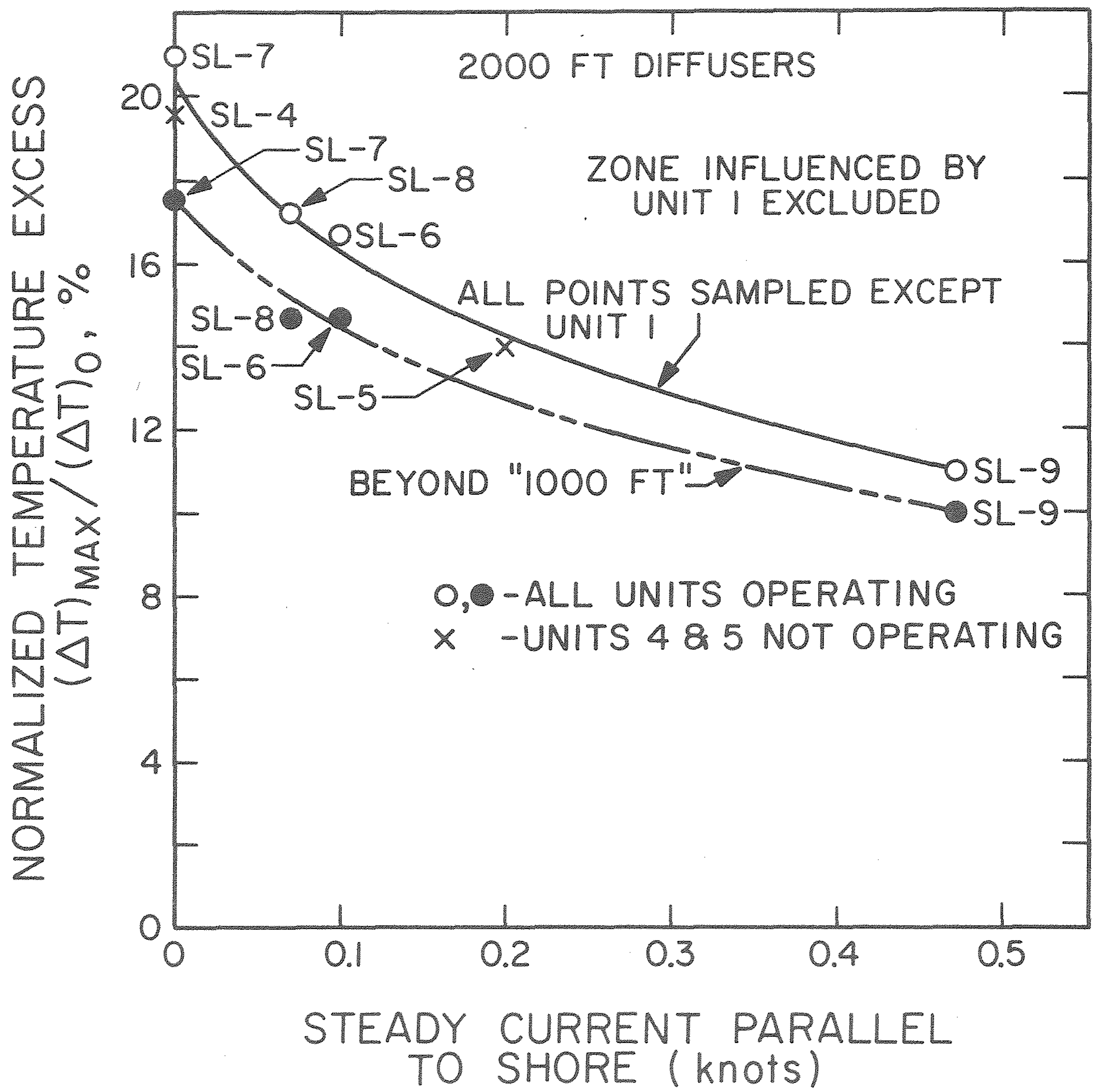


Figure 3.6 Summary of experiments on 2000 ft long diffusers (all tests for five units except x which are for three units [1 through 3]).

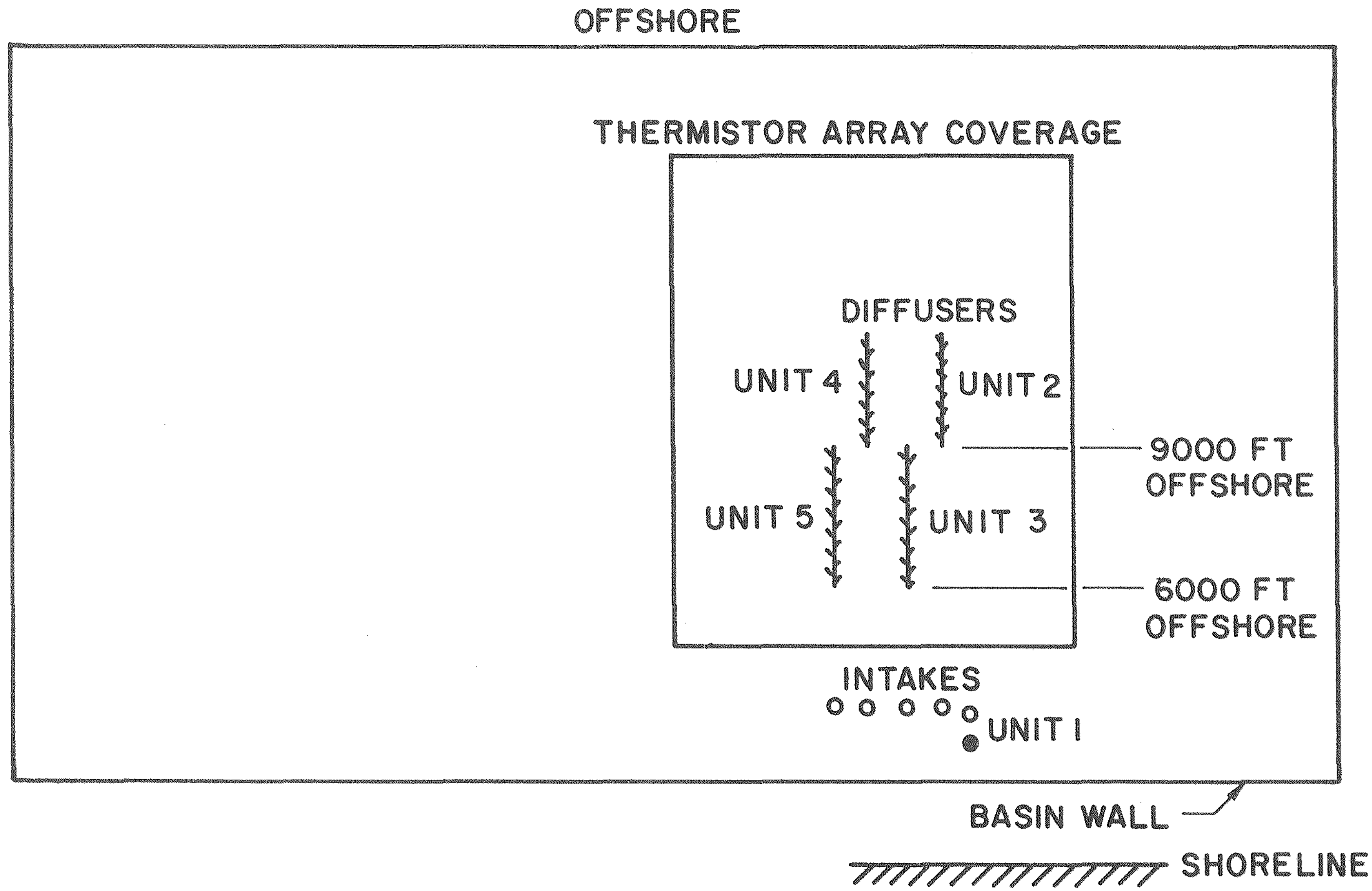


Figure 3.7 Schematic of basin layout for second set of perpendicular-to-shore diffusers.

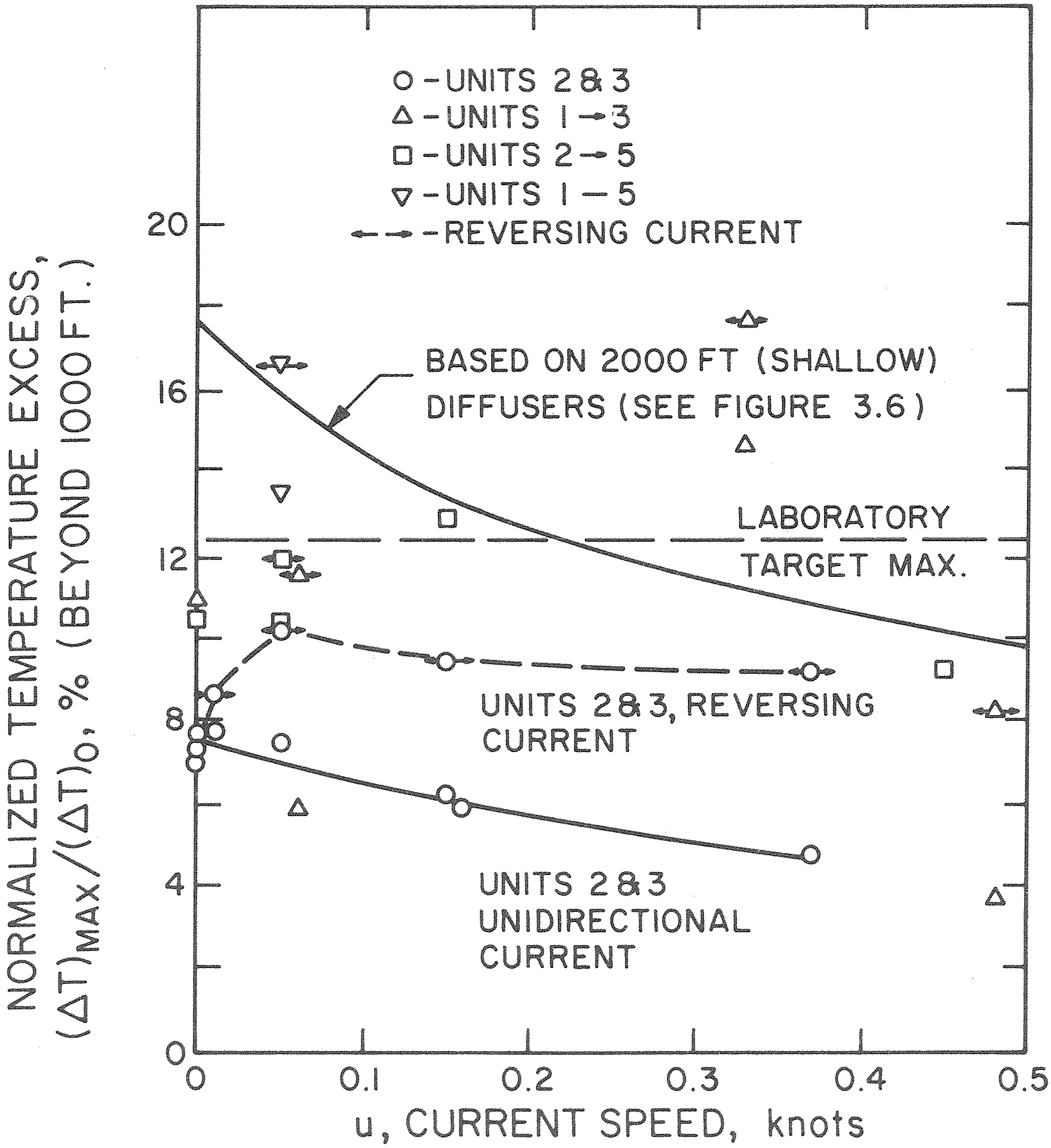


Figure 3.8 Summary of experiments on 2500 ft/3000 ft long diffusers. (For reversing currents, speed plotted is the maximum during the cycle.)

A total of 12 combinations of two diffusers (for Units 2 and 3) were possible - 4 distances offshore and 3 combinations of diffuser lengths. The results in Table 3.1 indicate that increasing depth of the diffusers is an effective way to reduce the maximum temperature excess (ΔT) whereas increasing the length of the diffuser at a fixed depth results in a relatively slow rate of decrease of ΔT. However, the cost of increasing the depth of the diffuser far exceeds the cost of increasing its length at a fixed depth due to the bathymetry at the site. The most economical solution is therefore not necessarily to place the diffuser into deeper water.

The results of 49 experiments (detailed in (3)) indicated that the N2 configuration (two 2500 ft long diffusers starting at 3500 ft offshore) represented the most economical pair of diffusers which would meet the laboratory target of $\Delta T/\Delta T_o \leqslant 12.5\%$.

(iv) Ocean currents

The systematic study of diffuser length and depth discussed previously was carried out for a variety of ocean currents including both steady and reversing currents. The results of that study indicated that: (1) for steady current tests, the maximum temperature excess (ΔT) decreased as the current speed increased; and (2) for tests with reversing current, ΔT was independent of the current amplitude. This latter result was not surprising since it was anticipated that for a reversing current the controlling situation for the maximum temperature excess would be during slack current.

Table 3.1

Comparison of Various Diffuser Configurations

(Values shown are (F_{max}/R_{max}))

$F_{max} = (\Delta T/\Delta T_o)_{max}$ anywhere *

$R_{max} = (\Delta T/\Delta T_o)_{max}$ outside 1000 ft limit *

Diffuser Configuration \ Distance Offshore	N	NM	M
u = 0			
1	14.2/10.6	12.1/10.3	9.8/8.9
2	14.2/11.7 12.4/ 9.0	10.6/10.3	8.3/7.5
3	12.0/11.3	9.2/ 9.2	9.9/9.9

u = 0.05 knot steady

	N	NM	M	F
1	14.0/12.2	10.8/9.6	10.6/10.1	9.9/8.4
2	12.5/ 9.7	10.3/9.5	10.5/ 9.3	9.2/7.2
3	10.4/ 9.1	8.9/8.9	9.1/ 8.5	7.5/7.5

u = 0.05 knot reversing

	N	NM	M	F
1	18.2/13.8	12.5/12.5	13.7/11.6	12.6/9.3
2	13.0/10.5	10.7/ 9.8	12.8/11.3	11.1/9.5
3	12.8/12.8	11.8/11.8	10.6/10.3	9.9/9.9

* Corrected for laboratory ambient temperature rise and difference in heat loss effect between model and prototype.

A systematic study of the effect of currents was also made for the final design obtained as an outcome of the laboratory study of diffuser length and depth, as later slightly modified for construction reasons. These tests were the final confirming tests as reported in the Project Report KH-R-30 cited previously (1). Table 3.2 presents the results of these tests. Currents SP1-SP4 are special currents selected from actual current records from the San Onofre site; the designation R on Runs C-16, C-17, C-18 refers to a current of the indicated amplitude reversing twice in each 12-hour prototype cycle (semi-diurnal tide). The results of these tests and also the tests of the N2 configuration from the previous tests are shown in Figures 3.9 and 3.10. These two charts show quite clearly that the effect of a steady ocean current is to reduce the maximum temperature excess. For oscillating currents, the maximum temperature excess appears to be independent of the current amplitude.

The measured surface isotherms for the case of zero ambient current are shown in Figure 3.11 and the surface isotherms corresponding to special current SP4 (Fig. 3.12) taken 20 minutes (22.5 prototype hours) after the commencement of the test is shown in Figure 3.13. The time sequence of the maximum temperature excess record for the test is shown in Figure 3.14. The fluctuating nature of the temperature excess record corresponds to the fluctuating nature of the special current. Photographs of the model diffusers in operation at various

Table 3.2

Summary of Surface Temperature Maxima in Confirming Tests

The field surface temperature increments (ΔT) are expressed as percentages of the temperature rise of the discharge (ΔT_c) for all the experiments in this series. The headings are explained as follows:

Run No.	Run sequence number
U	The prototype current speed in knots (R indicates reversing current with maximum = U; SP indicates special current).
F'_{max}	$(\Delta T/\Delta T_o)_{max}$ in percent, as measured anywhere in basin.
R'_{max}	$(\Delta T/\Delta T_o)_{max}$ in percent, as measured in basin beyond the 1000 ft limit (based on 787.5 horizontal scale).
F_{max}	F'_{max} in percent corrected for (a) ambient temperature due to finite basin size, and (b) difference in heat loss effect between model and prototype.
R_{max}	R'_{max} corrected for (a) and (b) above in percent.

Note: Details of corrections in F_{max} and R_{max} are discussed on pages and 41, 52, 58, 59, of Ref. (1).

		$\Delta T/\Delta T_o$			
		Uncorrected		Corrected	
Run No.	U (knot)	F'_{max} (%) (anywhere)	R'_{max} (%) (>1000 ft)	F_{max} (%) (anywhere)	R_{max} (%) (>1000 ft)
C-7	0.5	6.5	6.1	6.8	4.5
C-8	0.25	7.9	7.1	7.5	5.9
C-9	0.1	12.4	10.3	12.9	10.8
C-10	0.05	13.9	9.8	14.4	10.3
C-11	0	13.5	11.1	14.0	11.6
C-12	SP1	11.6	9.4	12.1	9.9
C-13	SP2	13.9	10.7	14.4	11.2
C-14	SP3	11.2	11.2	11.7	11.7
C-15	SP4	13.1	10.4	13.6	10.9
C-16	0.15R	11.3	10.4	11.8	10.9
C-17	0.05R	12.8	11.5	13.3	12.0
C-18	0.4R	11.9	11.0	12.4	11.5

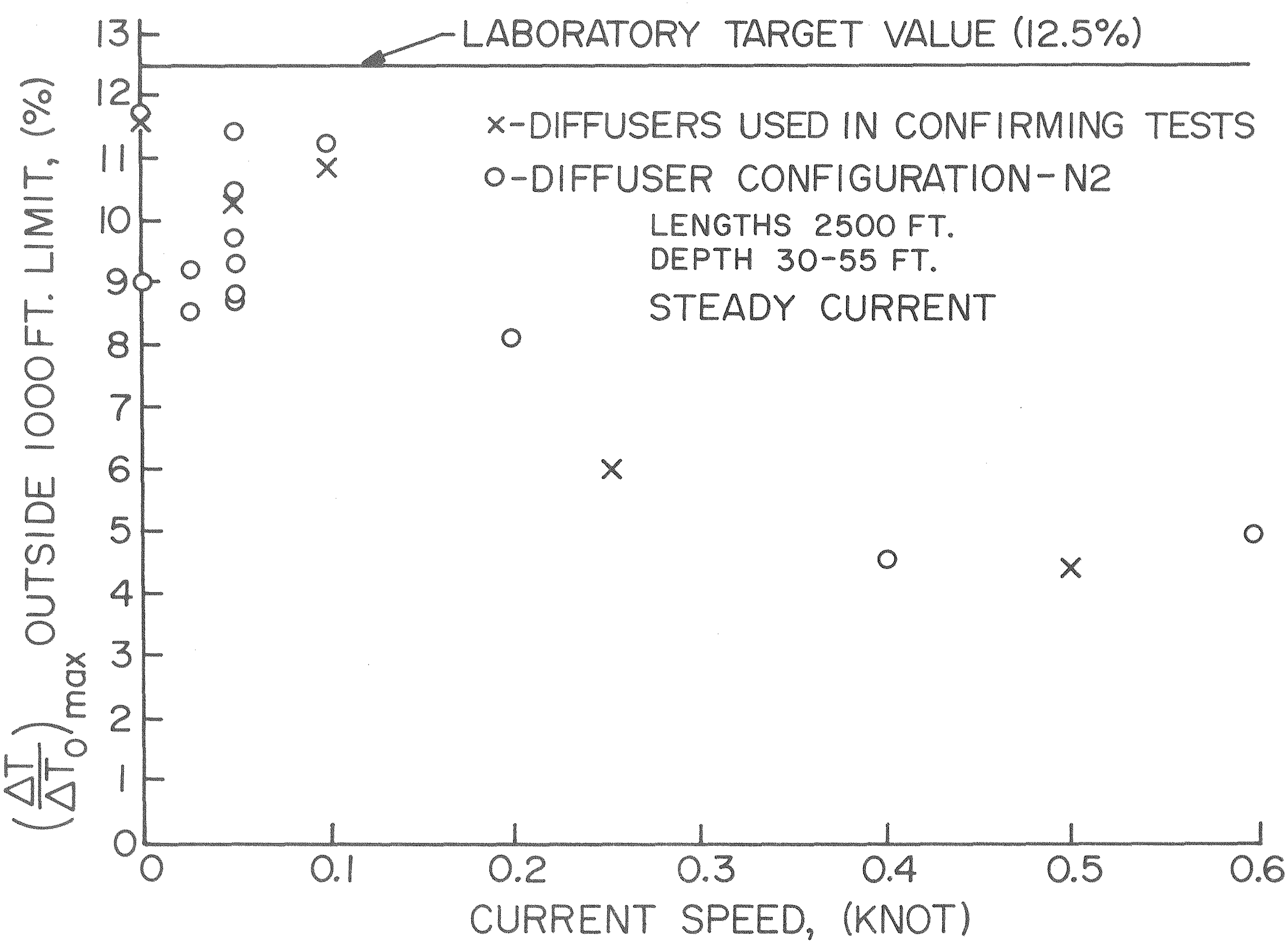


Figure 3.9 Summary of maximum surface temperature excess (beyond 1000 ft limit) as function of steady current speed.

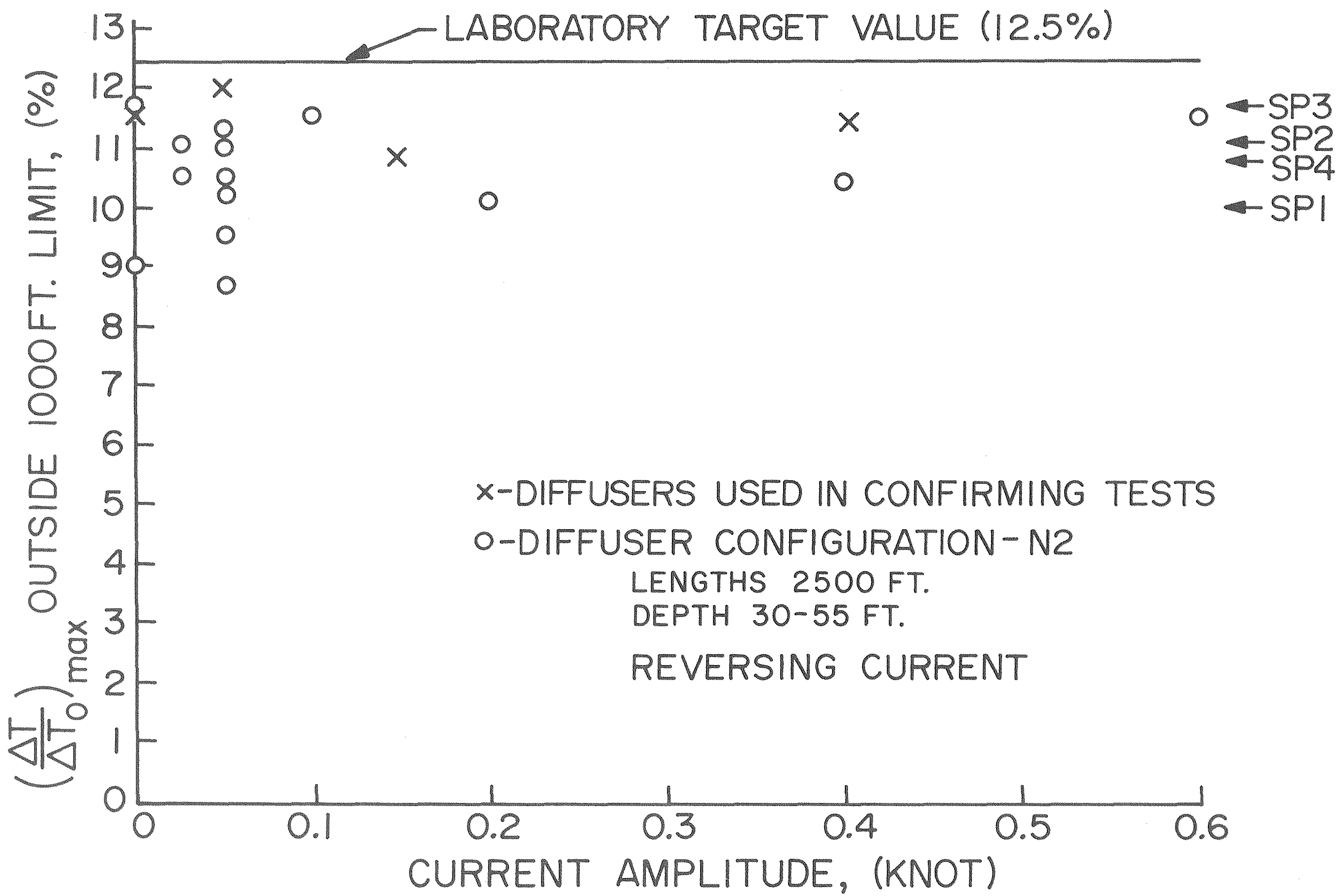


Figure 3.10 Summary of maximum surface temperature excess (beyond 1000 ft) as function of reversing current amplitude (special currents shown by arrows on right of figure since there is no clearly defined current amplitude).

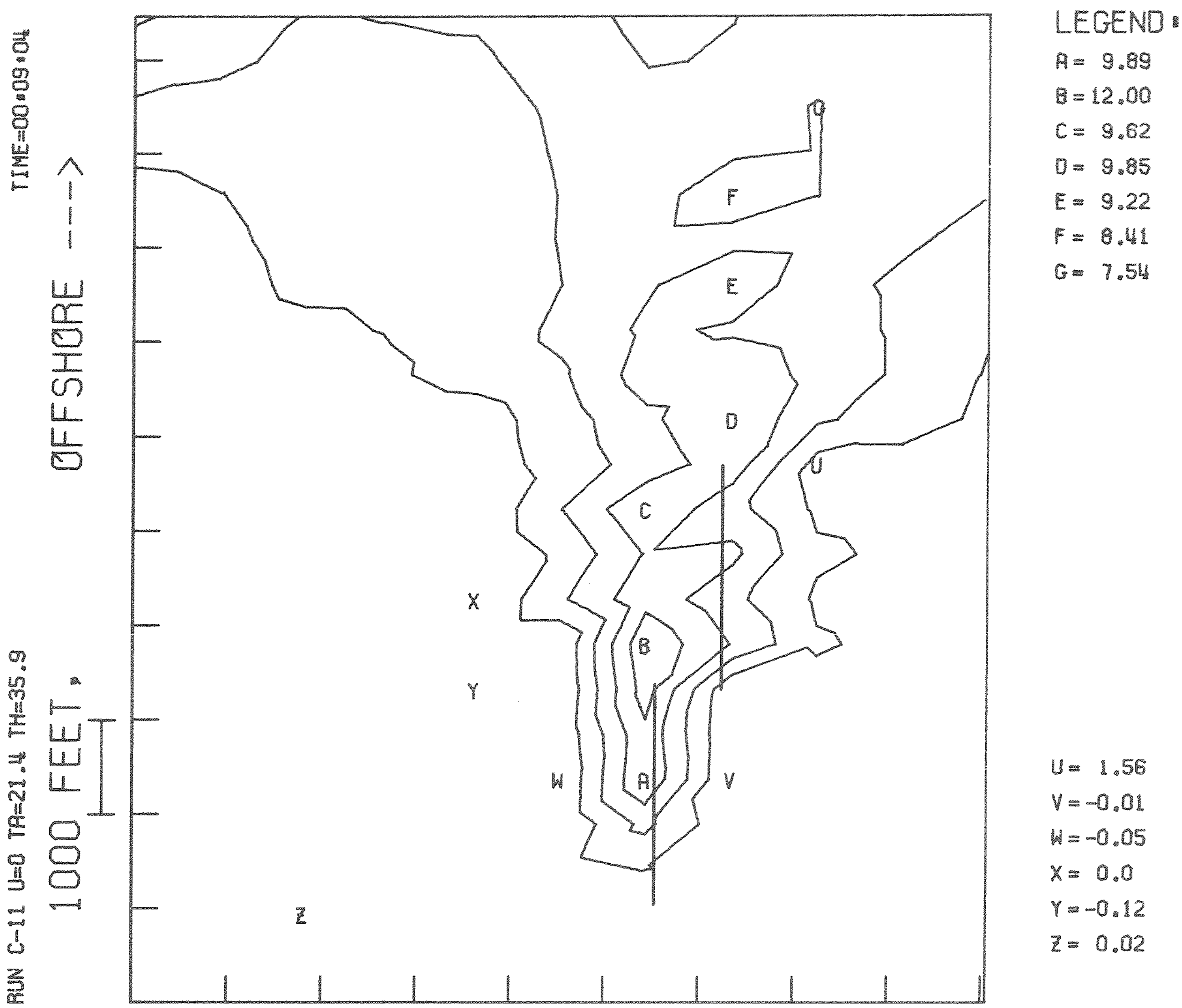


Figure 3.11 Surface isotherms (in increments of 2.5% of source ΔT_o) for steady ambient current u = 0.0 knots (diffusers shown as straight lines).

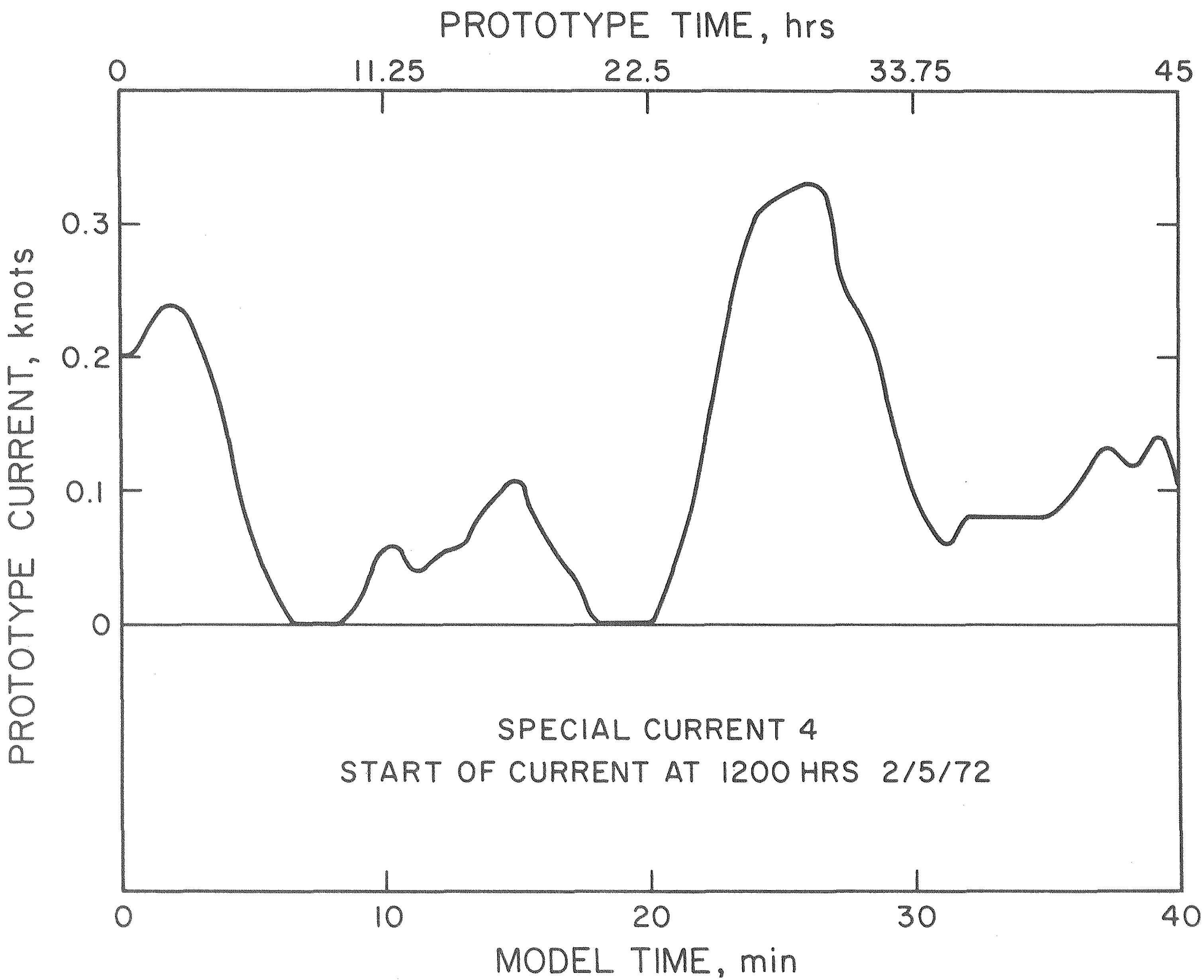


Figure 3.12 Longshore current sequence (SP4) used in Run C-15.

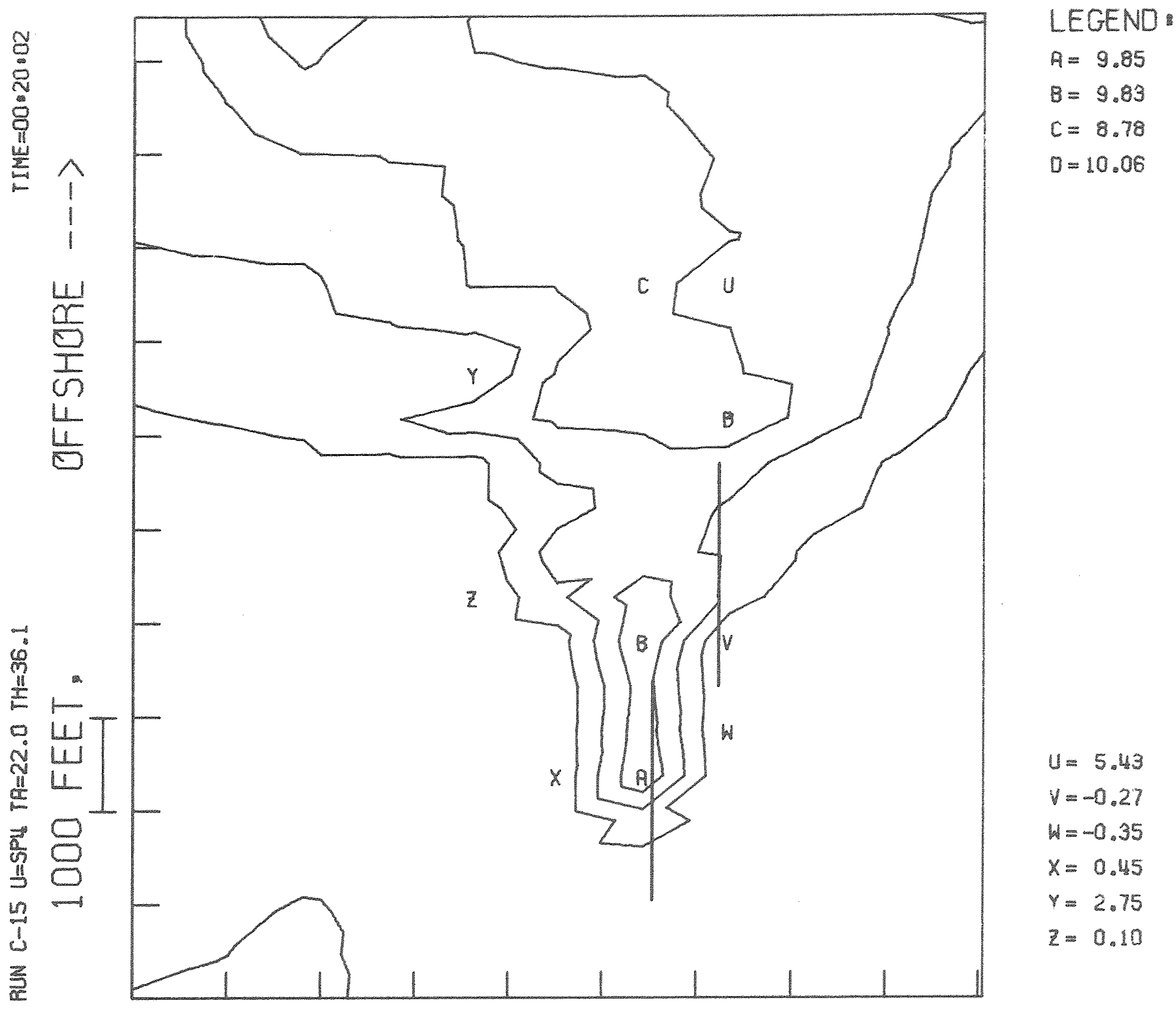


Figure 3.13 Surface isotherms (in increments of 2.5% of source ΔT_o) for special current sequence SP4 (Figure 3.12). (Diffusers shown as straight lines; instantaneous current speed = 0.0 knots.)

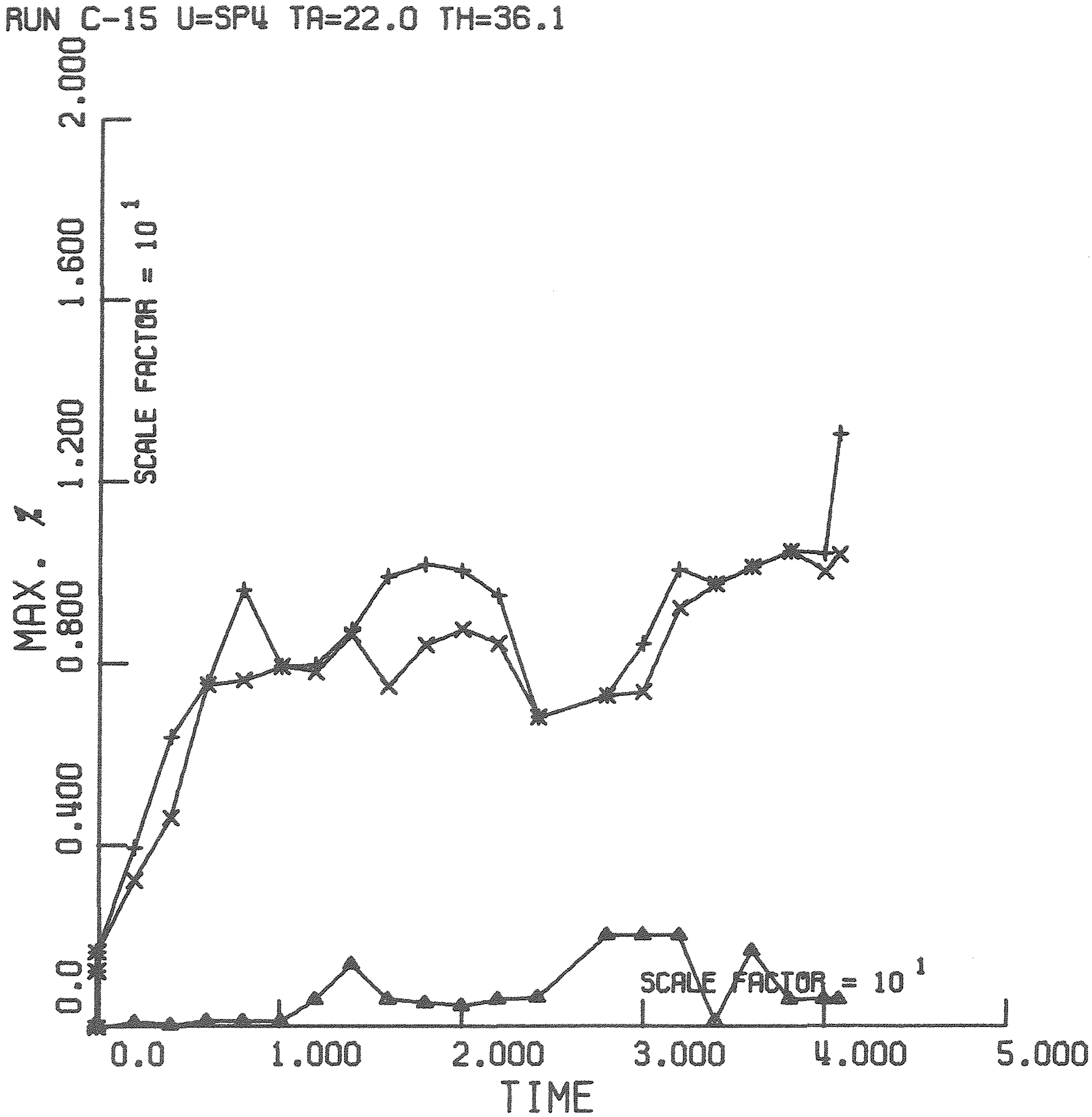


Figure 3.14 Summary of maximum temperature excesses (in % of source temperature excess) measured anywhere in basin (+), beyond 1000 ft of diffusers (x) and ambient temperature. (Run C-15, u = SP4, Figure 3.12)

current speeds are shown in Figures 3.15, 3.16, 3.17, and 3.18.

It is apparent from the results of these tests that the net effect of the offshore momentum is to prevent the build-up of heat in the neighborhood of the diffusers during periods of zero or low along coast current. Although the actual monitoring of temperature during a period of low current did not extend for a period longer than approximately 30 minutes in the model (34 hours in prototype) there is no reason to believe that the motion generated by the jetting action of the diffuser would result in any local heat build-up even if the period of zero current extended for a period of several days.

3.3 Test of Modeling Procedures

The preceding hydraulic model test results all indicate that, for the site conditions modeled, the diffusers as designed will meet the laboratory target of $\Delta T/\Delta T_o \leqslant 12.5\%$. The questions to be resolved are whether the modeling process and procedures do result in a valid representation of the actual prototype situation or, given that some procedure is recognized to be inadequate in some way, will it result in a conservative prediction of the maximum temperature excess to be anticipated.

The dimensionless variable of primary importance in the model is the densimetric Froude number, which in effect relates the relative magnitude of the momentum (inertia) forces to the buoyancy forces. Other variables are: the Reynolds number, which governs the importance of viscosity; the geometrical

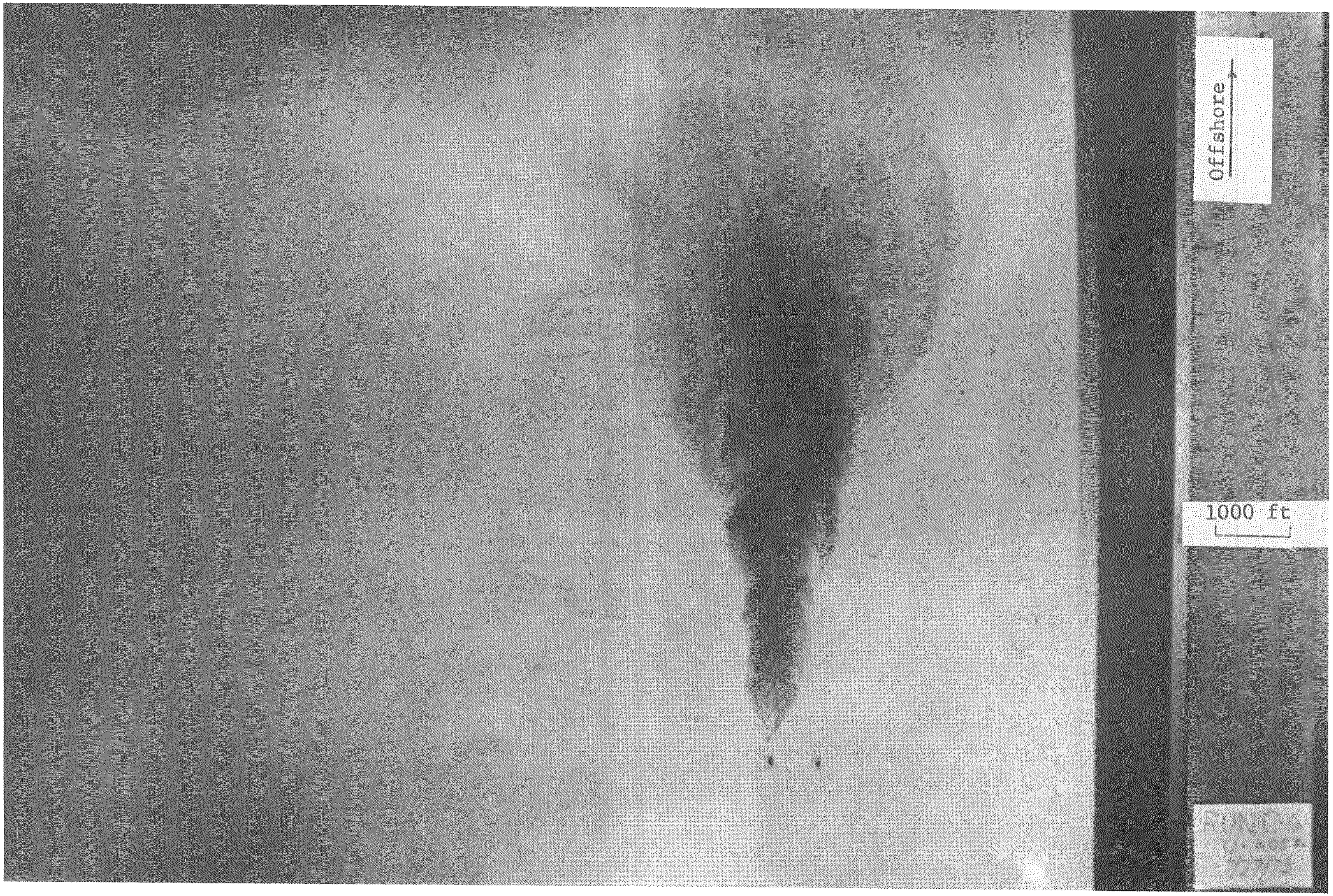


Figure 3.15 Overhead photograph of warm water dispersion for ambient along-shore current speed = 0.05 knots.

Figure 3.16 Overhead photograph of warm water dispersion for ambient along-shore current speed = 0.1 knots.

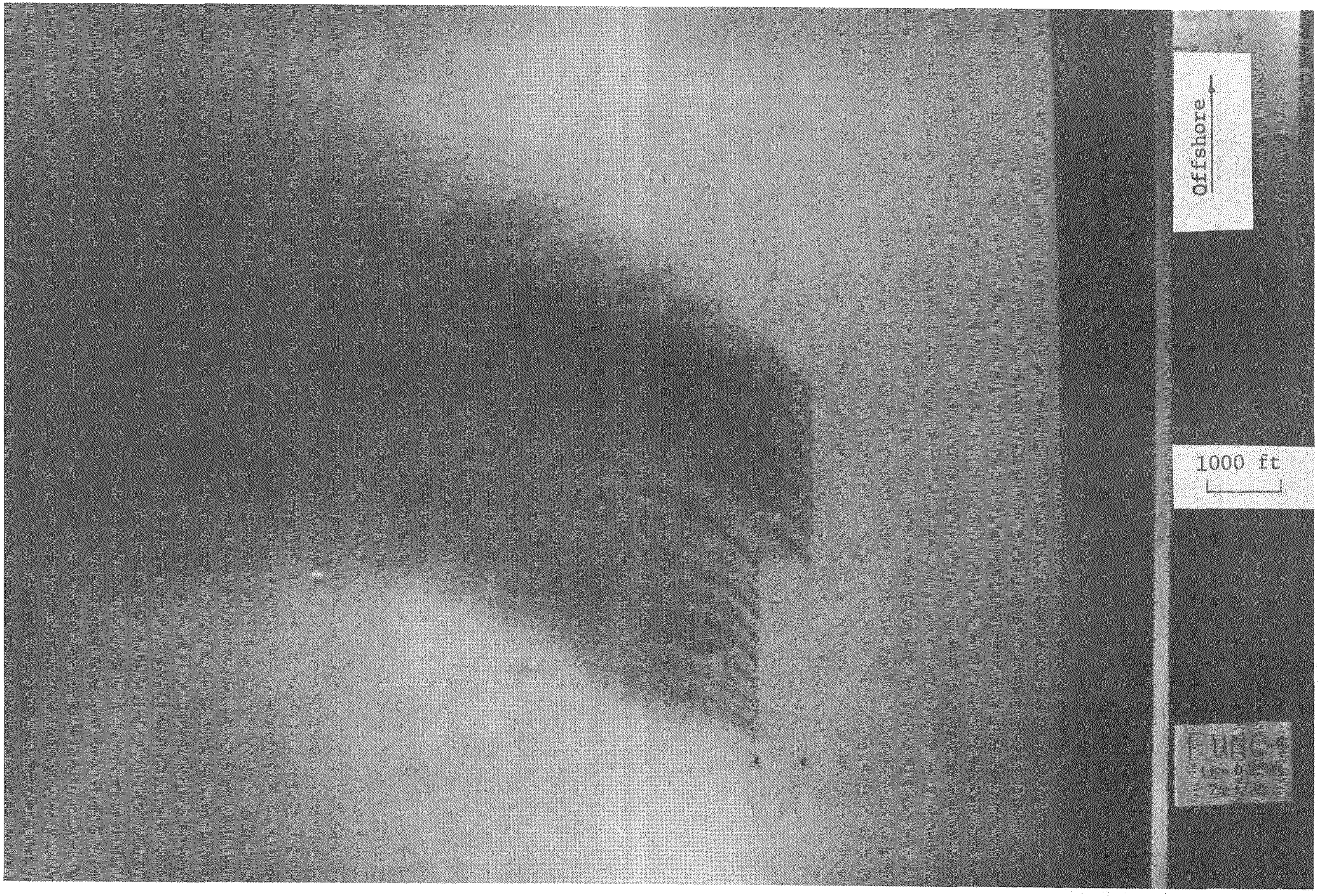


Figure 3.17 Overhead photograph of warm water dispersion for ambient along-shore current speed = 0.25 knots.

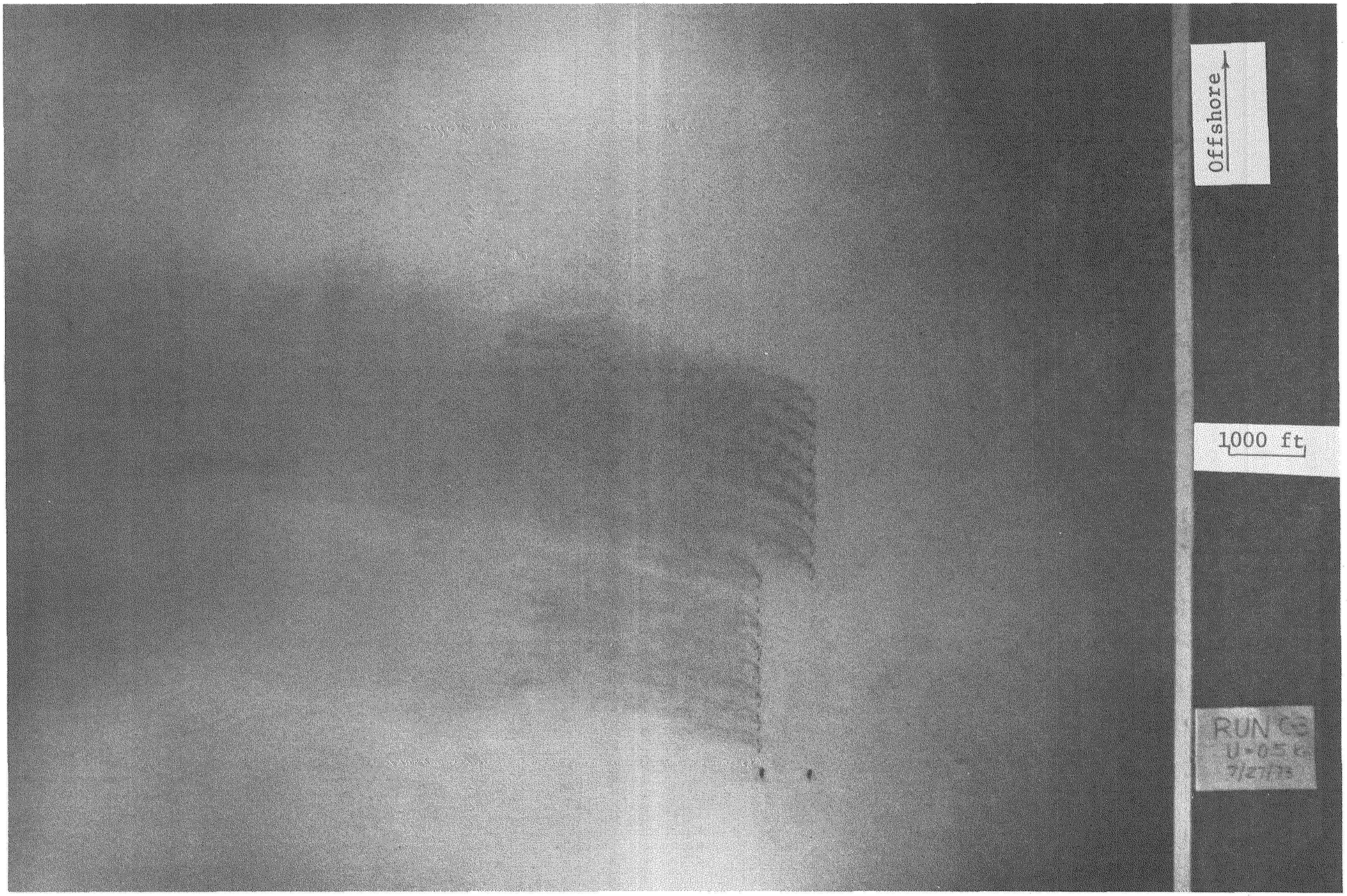


Figure 3.18 Overhead photograph of warm water dispersion for ambient along-shore current speed = 0.5 knots.

ratios defining the relative dimensions of the problem; and the ratio of discharge velocity to ocean current velocities. In the modeling process it is not possible to keep all the dimensionless numbers the same between model and prototype and some compromises must be made. There are various reasons for this which will not be discussed in detail (they are described in (1)). These compromises however must either be directly checked or be shown to be conservative to guarantee model credibility.

The particular problems associated with the San Onofre hydraulic model were:

(i) Distortion of scales

Undistorted models have relatively too much bottom and interfacial friction compared to the prototype because the model Reynolds numbers are much smaller than the prototype and often indicate laminar flow. This problem is overcome by distorting the vertical to horizontal length scales by a factor of 4, i.e. the hydraulic model is made four times as deep as it would be for a scaling based on horizontal dimensions. This distortion is deemed essential to maintain proper simulation of frictional effects. The number of diffuser jets is reduced by a factor of 4 (the distortion ratio), in order to maintain an undistorted flow pattern for the individual jets, even though the ratio of diffuser length to depth is reduced by a factor of 4 also. This type of distorted modeling is legitimate only if the number of model ports is still large (16 in this case) and the ratio of diffuser length to depth is still high (~15 in this case). The net effect is that the appropriate ratio on which to scale any measured isotherms will lie somewhere between the vertical scaling and the horizontal scaling. Since the horizontal scaling is the larger, (bigger prototype-to-model ratio), the surface isotherms plotted on this scale will give conservative results.

The effect of this scaling distortion was investigated systematically by not only changing the distortion ratio while keeping the horizontal or vertical scale fixed, but also by varying the scales with the distortion ratio fixed. In these special tests, only one San Onofre diffuser was simulated at horizontal scales of 800 and 400, and vertical scales of 200 and 100. Thus, four combinations of scales varying in distortion from 8 to 1 to 2 to 1 were investigated. It may be noted also that there were two combinations which both lead to a 4 to 1 distortion, (i.e. 800/200 and 400/100). The water depth was held constant throughout the basin to eliminate any effect of shoaling bathymetry and the simulated prototype depth was 47 feet.

Surface thermal maps were taken at intervals of three hours simulated prototype time and steady longshore currents of 0, 0.15 and 0.4 knots were used in the tests. Figures 3.19 through 3.21 show representative surface isotherm plots (at 9 hours simulated prototype time) for these cases. Each isotherm represents an increment of 2.5% of ΔT_o. The

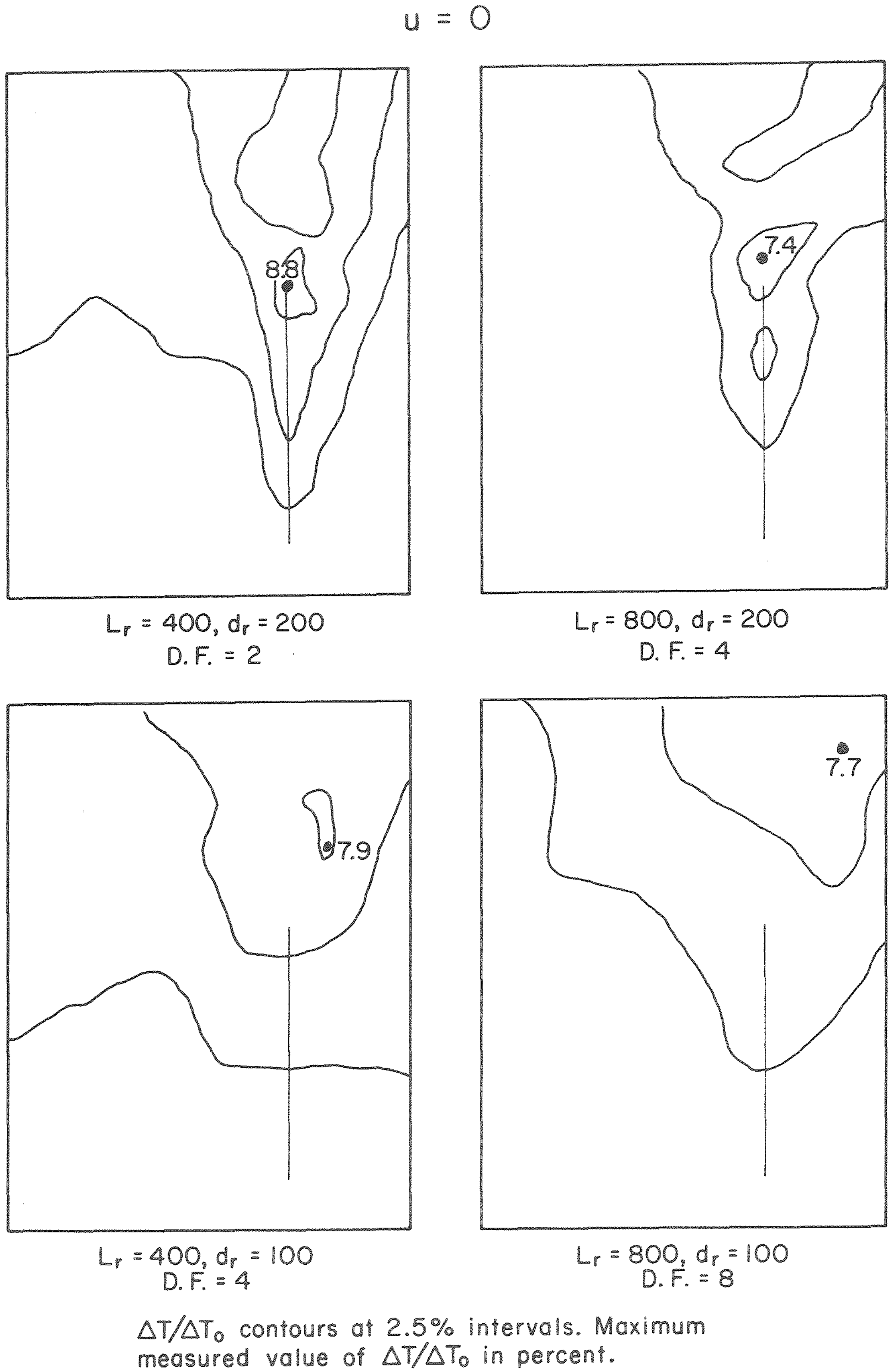


Figure 3.19 $\Delta T/\Delta T_o$ contours at 2.5% intervals. Maximum measured value of $\Delta T/\Delta T_o$ in percent.

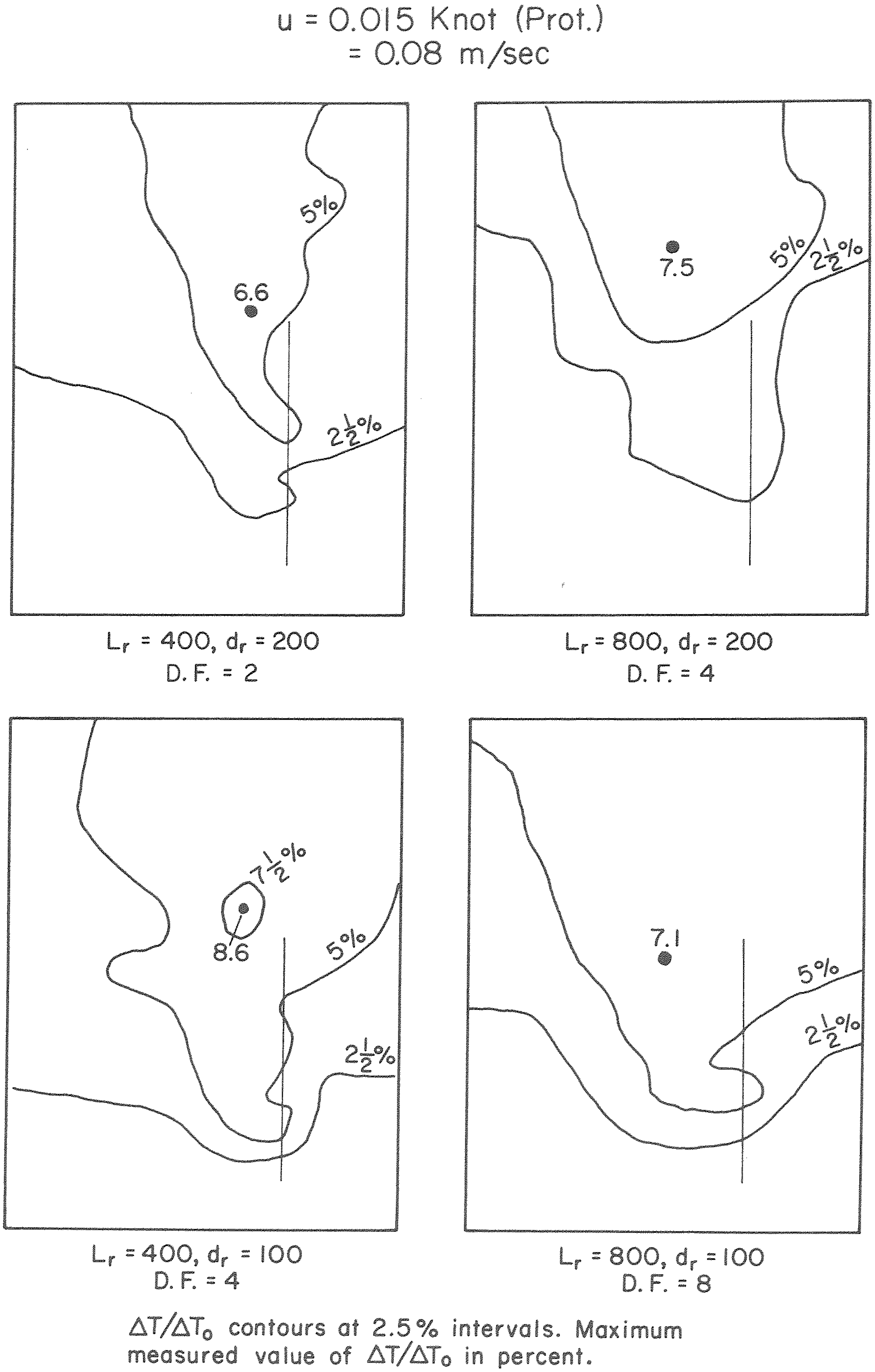


Figure 3.20 $\Delta T/\Delta T_o$ contours at 2.5% intervals. Maximum measured value of $\Delta T/\Delta T_o$ in percent.

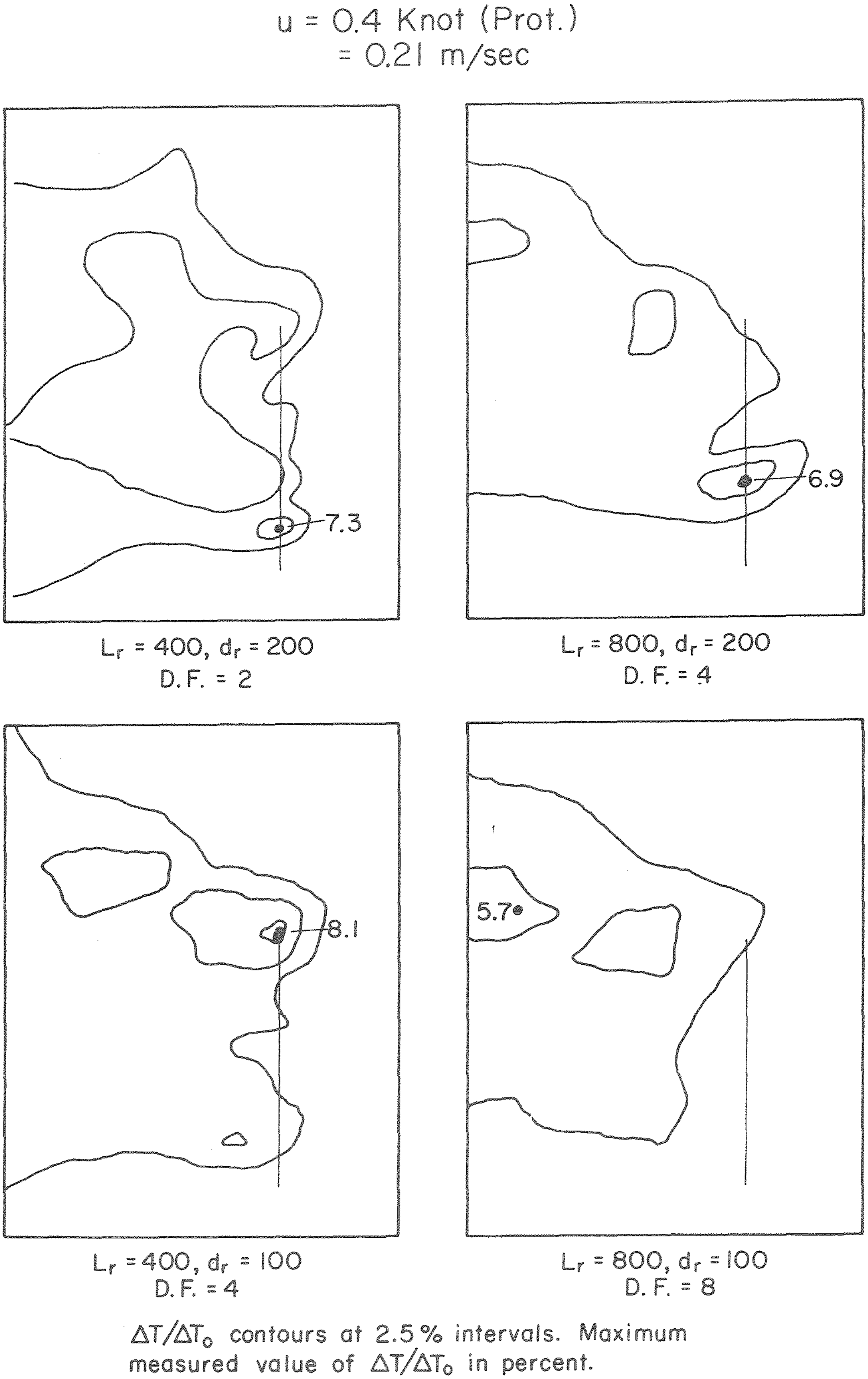


Figure 3.21 $\Delta T/\Delta T_o$ contours at 2.5% intervals. Maximum measured value of $\Delta T/\Delta T_o$ in percent.

maximum sampled surface temperature is also indicated in each figure. From these figures it is seen that both scale and distortion have an effect on the results, the variation being on the order of 1-2% of ΔT_o. For $\Delta T_o = 20°F$, the effect of distortion and scale in the range tested is of the order of 0.2 to 0.4°F. It should be noted that random experimental errors in the basin tests as illustrated in Figures 3.9 and 3.10 are of the same magnitude.

(ii) Reynolds number of jets

The diffuser jet diameters were modeled according to the vertical scale ratio. If the diffuser jets were to remain turbulent the minimum model jet diameter is fixed by the minimum jet Reynolds number at which the jets would be fully turbulent; the corresponding maximum vertical scale was determined to be about 200:1.

In order to check that the dilutions produced by each individual diffuser jet were being modeled correctly, a small section of the diffuser was also modeled at a nominal undistorted scale of 50:1. The results of tests with this section of the diffuser indicated that dilutions slightly in excess of those occurring in models with larger vertical scales could be expected (Ref. (9)). For tests with steady currents ranging from 0 to 0.2 knots (prototype), the peak temperature increments at a distance of 120 feet from the diffuser ports were found to be in the range of 7.5%± 1.5% of ΔT_o for the 50:1 sectional model. This result should be compared to the 9.5%± 2% of ΔT_o determined in the distorted model tests of the entire diffuser system at the same current speeds.

The sectional model therefore, clearly demonstrated that the jet mixing induced by the individual jets is fully capable of producing the dilutions implied by the basin model tests of the entire diffuser. The smaller dilutions obtained in the basin model probably arise from the overall flow pattern and jet interference and lower jet Reynolds number. The results obtained in the basin models are therefore conservative.

(iii) Reynolds number for the ocean current

There is no practical way that the Reynolds number of the ocean based on depth could be reproduced in the laboratory. The effect of this is twofold. First, the Reynolds number affects the interfacial and bottom friction. This effect is corrected for by the distortion of scales. Second, the fact that the ocean turbulence is much higher probably means that the dispersive spread is greater in the ocean. In particular the horizontal shearing motions induced by the larger scale eddies are probably responsible for most of the dispersion and these are not represented in the laboratory. It seems safe to conclude that this effect tends to make the maximum temperature excesses that occur in the laboratory higher than they would be in the prototype.

(iv) Ocean density stratification

The laboratory tests did not include the effect of any naturally occurring ocean temperature stratification. It is apparent that any gravitationally stable temperature stratification will result in lower maximum temperature excesses in the field than would occur if the ocean were homogeneous in temperature. The effect of this will be such as to make the laboratory results conservative as will be discussed in more detail subsequently in Section 4.

(v) Surface heat losses

The rate of surface heat loss occurring in the laboratory was in excess of that occurring in the field. This fact lead to a small systematic correction being applied to the predicted isotherms obtained in the laboratory. The problem of field surface heat transfer will be discussed in more detail in Section 4.

(vi) Confirmation of undistorted modeling process

Field monitoring data were available for the existing Unit 1 discharge at San Onofre and therefore experiments were conducted in the laboratory that would make available laboratory predictions for the same field conditions. The results of these tests of Unit 1 indicated that the modeling process was appropriate, at least at the scale (100:1) and flow rates chosen for those tests. These tests were done with an undistorted model since it is not possible to model correctly a single point discharge such as Unit 1 in a distorted model. Thus while the confirmation of field results is indicative of adequate modeling for undistorted models and does not guarantee the validity of the distorted models, it does lend credibility to the concept of densimetric Froude number similarity.

Another way to gain confidence in model-prototype relations is to examine the performance of similar projects for which prototype data are available to compare with the model predictions. Unfortunately, there are no such projects from which to get experience. The Browns Ferry Nuclear Power Plant has diffusers located in the Wheeler Reservoir on the Tennessee River and Quad Cities Nuclear Plant has diffusers in the Mississippi River. These flow situations are not at all similar to San Onofre, and furthermore both plants are being required to use closed circuit cooling for much of the time.

The outfall for the Fitzpatrick Plant on Lake Ontario might be most closely related to San Onofre although the diffuser is much shorter with fewer ports and parallel to shore. No field data are yet available as its operation has barely started.

3.4 Error Analysis for Laboratory Tests

The task of translating the laboratory test results to the operation of the prototype in the field is complicated by many factors. The selection of the laboratory target value of $\Delta T \leq 2.5°F$ was in response to the recognition of these problems. However, as stated in Section 3.1, the 2.5°F laboratory target value was selected before any experiments had been done in the laboratory. It was based on the investigator's best judgment, at that time, of the influence of these various factors.

One outcome of the laboratory experiments is that the sensitivity analysis of the results to various changes in design variables has enabled better estimates to be made of the possible discrepancies between the laboratory results and the prototype behavior. It will be noted from the discussion of the laboratory tests above that some of the factors that will influence the operation of the prototype could not be modeled in the laboratory under any circumstances. These effects will be considered in greater detail in Section 4.

The errors in the laboratory results can be summarized as follows:

(i) Random errors arising from errors in temperature measurement, current velocities, calibration procedures, and the like were found to be ±2% of ΔT_o. The best estimate of the maximum temperature excess (beyond 1000 ft) expected from the laboratory studies was 9.5% ± 2% of ΔT_o (1.9°F ± 0.4°F) (corrected for laboratory heat loss).

(ii) Scaling and distortion errors can be assessed from the results of tests in which both scaling and distortion ratios were varied. There was no net change indicated in the expected value of the maximum temperature excess and the results showed a variation of ±2% (±0.4°F) which is believed to be random error as above.

(iii) Jet Reynolds number, and jet interference errors can be estimated from the results of the 50:1 undistorted sectional model tests, which showed the maximum excess to be 7.5% ± 1.5% of ΔT_o compared to 9.5% ± 2% for the distorted model tests at 200:1 vertical and 800:1 horizontal for steady currents in the range 0 - 0.2 knots. It is believed that a conservative estimate for the error introduced from jet Reynolds number and jet interference will therefore be to assume no modification of the results in the larger scale ratio tests.

It can, therefore, be concluded that if the laboratory results were applied to a field situation that was exactly represented in the laboratory the maximum likely temperature excess (beyond 1000 ft) would be given by the following estimate

Random errors in modeling	±0.4°F
Allowance for scaling and distortion errors including jet Reynolds number and jet interference etc. (shown to be conservative)	±0.0°F
Total laboratory errors	±0.4°F
Best laboratory estimate for temperature excess	1.9°F ± 0.4°F

Estimates of the errors associated with the laboratory tests not being a true representation of actual prototype conditions will be considered in Section 4.

4. PROJECTED PROTOTYPE BEHAVIOR

In transferring the laboratory test results to the prototype it must be emphasized that certain field conditions could not be represented in the laboratory model and therefore some analysis of the influence of these factors must be made. This section is an attempt to provide a best estimate on the performance of the prototype diffusers by using both laboratory and field data to give bounds on the diffuser performance. These results will then be combined with the laboratory results to give a prediction of the prototype performance under field conditions. The possible unmodeled field influences are considered in turn.

4.1 Effect of Unit 1 Discharge on Units 2 and 3 Discharge Plumes

The effect of Unit 1 discharge on the isotherms predicted for Units 2 and 3 discharge plumes can be bounded by assuming either that Unit 1 discharge is entrained, without any heat loss, directly into Unit 3 discharge jets or alternatively, that Unit 1 discharge is carried over Unit 3 without dilution. Consider first the entrainment case, based on the Unit 3 diffuser which is the closer to Unit 1. Given that Unit 3 discharge is 1850 cfs at a temperature increment of 20°F and that Unit 1 discharge is 730 cfs at a temperature increment of 20°F, then ΔT^*, the temperature increment after dilution is

$$(\Delta T^* + T)\ 1850\ (1 + \alpha) = 1850\ (T + 20) + \left(\alpha - \frac{730}{1850}\right) 1850\ T + 730\ (T + 20)\ ,$$

where T is the ambient temperature and α is the number of volumes of diluting water entrained into the discharge plume by the diffuser jets. When Unit 1 is not operating then

$(\Delta T + T)\ 1850\ (1 + \alpha) = 1850\ (T + 20) + \alpha\ 1850\ T$, where ΔT is the temperature increment after dilution. From the experimental results ΔT is less than 2.5°F implying that $\alpha \gtrsim 7$. Thus we can calculate ΔT^* as being less than 3.5°F. In other words, the maximum additional temperature excess that could occur, assuming that all the heat discharged from Unit 1 were entrained in the discharge jets of Unit 3 would be less than 1°F. In actuality this case is impossible because the Unit 1 discharge plume is a thin surface layer whereas the diluting water is taken from the full depth; but by interpolation it can be seen, for example, that a 50% recirculation will give an increase in ΔT of 0.5°F.

The second possible effect of Unit 1 can be obtained by assuming that none of Unit 1's discharge becomes diluting water for Unit 3 but that the plume from Unit 1 is carried over Unit 3 by the motion induced by the jetting action of Units 2 and 3. The Thermal Effect Study Final Summary Report (4) contains data indicating the frequency with which 4°F and 1°F isotherms from Unit 1 extend a given distance from the outfall (Figure 4.1). The data indicate that the likelihood of the 4°F isotherm extending beyond 2000 ft from the Unit 1 discharge is less than 2%. The maximum observed limit of the 4°F contour is shown on Figure 4.2. Superimposed on this figure are the locations of Units 2 and 3 diffusers from which it can be seen that the Unit 1 plume will extend over the Unit 3 diffuser on occasion. This will occur even without the

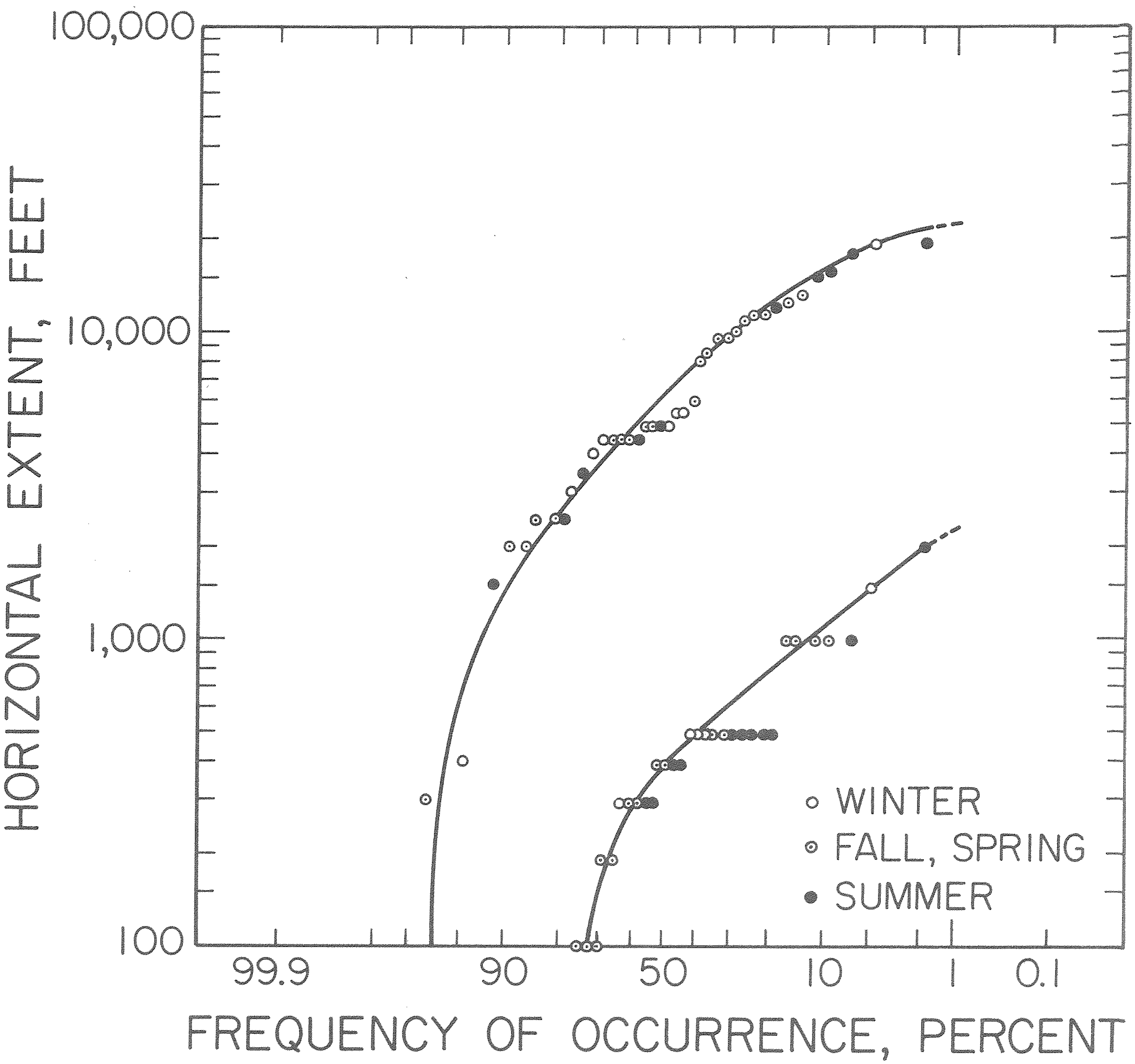


Figure 4.1 Frequency with which observed horizontal extent of elevated temperature was equalled or exceeded, (Ref. (4)) San Onofre Unit 1.

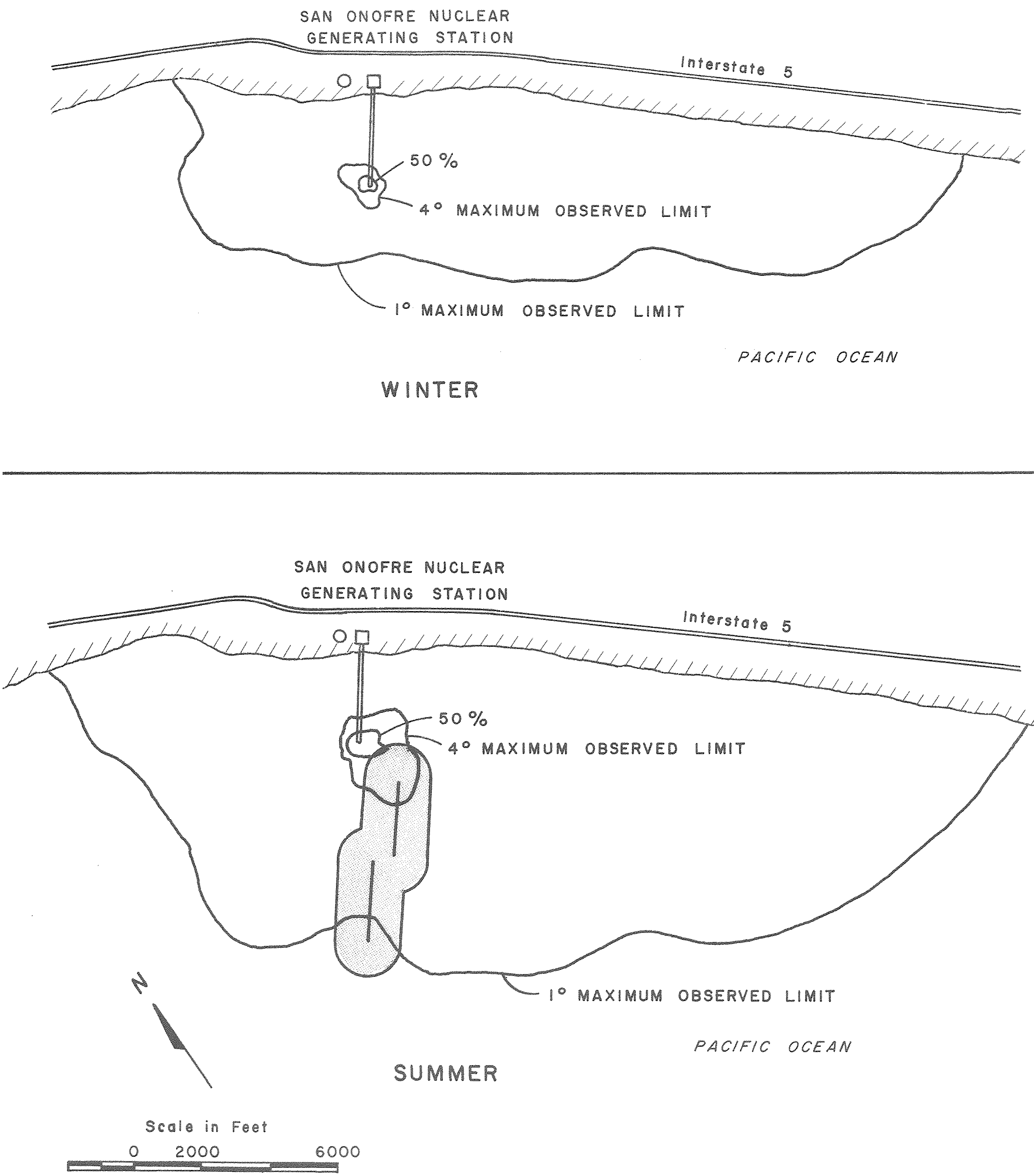


Figure 4.2 Observed limit of horizontal extent of 4°F and 1°F elevated temperature contours (Ref. (4))

offshore current induced by the Unit 2 and 3 diffusers. The 50% occurrence contour, on the other hand, does not extend over the 1000 ft perimeter from Unit 3.

It must be cautioned, however, that these limits of occurrences of zones of $\Delta T = 4^\circ F$ and $1^\circ F$ shown in Figures 4.1 and 4.2 were based on a specific method of choosing the baseline or "natural" temperature (Ref. 4). It has been demonstrated in Ref. (5) that the temperature in the near-shore waters off the southern California coast varies both spatially and temporally. Based on examination of the available field data, it was estimated that fluctuation in natural temperatures is of the order of $\pm 2^\circ F$ in summer (June through September) and $\pm 1^\circ F$ during the other months. Thus, the interpretation of the significance of these limits (in Figures 4.1 and 4.2) must be somewhat qualitative. An error of $1^\circ F$ in the estimation of the natural temperature can introduce a heavy bias in the limits as shown.

4.2 Offshore Transport Induced by Diffuser Momentum

The net effect of the diffuser will be to induce a current directed offshore. In periods of low ambient currents this induced current will be a significant factor in removing heat from the neighborhood of the diffusers. An estimate of the speed and extent of this current can be obtained by considering the trajectory of the diffuser discharge in the laboratory results when a cross current is present. Figures 3.16, 3.17 and 3.18 show the diffusers in operation in cross currents of 0.1, 0.25 and 0.5 knots respectively. Assuming that the deflection angle of discharge, θ, is approximately related to the ratio of the cross current velocity and the mean diffuser current by

$$\tan\theta = u_a/u_d \ ,$$

then for each of the currents imposed it is found that:

u_a(knot)	θ	u_d(knot)
0.1	30°	0.175
0.25	55°	0.175
0.50	70°	0.182

It can be concluded that a reasonable estimate of the magnitude of the discharge induced offshore current is of the order of 0.18 knot or about 0.3 ft/sec. Temperature measurements show that when there is no ambient current the peak temperature increment recorded is about 2°F beyond the end of the diffusers and the surface plume width is about 3500 feet. This indicates that in the absence of surface cooling the initial dilution is about 10 times the total volume rate of flow associated with the discharge and is therefore of the order of 35,000 cfs. The mean depth of the discharge is therefore of the order of 35 feet. This estimate compares well with the vertical temperature profiles shown in Figure 6.8 of Reference (1).

It can therefore be concluded that when no ambient longshore current is present the discharge induced by the diffusion structures at the end of the diffusers some 8500 feet offshore will appear as a current of about 0.3 ft/sec of the order of 3500 feet wide and 35 feet deep. The total discharge will be of the order of 35000 cubic feet per second.

4.3 Effect of Offshore Momentum on Reentrainment

The possibility that the thermal discharge from the outfall diffusers for Units 2 and 3 could later become the diluting water for subsequent discharge, thus leading to a temperature build-up, must be considered. For example, one could envisage the effect of oscillatory tidal currents to be to carry previously discharged water back to the neighborhood of the diffusers to become part of the diluting water for the later discharge. Just such an eventuality as this served as the primary incentive for the development of a design that utilized the discharge momentum to direct the discharge offshore. In this way oscillatory tidal motion would not carry the discharge back over the diffusers since the offshore momentum delivered to the discharge would provide a continuous component of offshore velocity, amounting to an offshore displacement of 1080 ft/hr. A further point of significance is that the discharge being warmer, and therefore of lower density than the ambient water, would form a surface layer. Since almost all of the water providing the dilution of the discharge jets is from below the surface, any motion of the surrounding sea which ultimately returned diluted discharge to the discharge point would only bring it back at the surface, where it would not be significantly incorporated as diluting water. The likelihood of this occurring is considered to be very remote because of the net momentum imparted to the discharge by the diffuser jets.

The net offshore discharge caused by the diffusers must induce lateral currents parallel to the shore and these mean lateral currents must be such that 18,000 cfs is transported from each side of the diffusers across a mean depth in excess of 35 feet over a length of about 8500 feet; this means a mean lateral current of approximately 0.05 ft/sec. Such currents are barely perceptible with the usual type of flow metering devices. During periods of stronger lateral currents, of course, most of the entrainment water will be obtained from one side or the other of the diffuser.

The question of the interaction of the diffuser induced motions with naturally occurring motions in the ocean will be further considered in Section 4.6.

4.4 Possibility of Recirculation of Thermal Effluents Through Intakes

Because of the existence of the offshore current induced by the jetting action of the diffusers it seems highly unlikely that the discharge from Units 2 and 3 diffusers will be drawn into the Units 2 or 3 intakes. However, in view of the location of the Unit 1 discharge, and the existence of the induced offshore flow, a portion of the Unit 1 discharge may flow into the Units 2 and 3 intakes. The potential for this type of recirculation was investigated experimentally in a 100:1 scale model of the intake and discharge for Unit 1 and the intakes of Units 2 and 3. These tests were reported in Reference (1) and will be briefly reiterated here.

At the modeling scale of 100:1 it was not possible to reproduce identically the currents induced by the Units 2 and 3 diffusers, the reason being that each diffuser would be of the order of 25 feet long and could not be accommodated in the test basin. However, it was possible to estimate the range of possible currents that would be induced by the diffusers and arrange suction manifolds in the basin in such a way as to model the effect of a range of diffuser induced currents. Table A-7 of Reference (1), reproduced here as Table 4.1, gives the results of these tests. It can be seen that the recirculation of Unit 1 discharge into the proposed Units 2 and 3 intakes can lead to a temperature rise of probably no more than 0.5°F in the temperature of the water entering the intakes. The maximum temperature increment

Table 4.1

Temperature Rise in Intake Water (Recirculation Test), % of Discharge Temperature Excess

(Values given are for the test period equal to t_e, time it takes for a particle of water to travel the length of the basin and through the return circuit.)

Ocean Current Speed (knots)	Offshore Suction# → / t_e(min) (elapsed time until basin water returns)	UNIT 1 INTAKE NONE	UNIT 1 INTAKE HALF*	UNIT 1 INTAKE FULL**	UNIT 2 INTAKE NONE	UNIT 2 INTAKE HALF*	UNIT 2 INTAKE FULL**	UNIT 3 INTAKE NONE	UNIT 3 INTAKE HALF*	UNIT 3 INTAKE FULL**
		$\Delta T/\Delta T_o$ in percent								
0	>25	5.9			1.3			0.3		
0.05	>25	4.8	4.9	5.7	3.4	0.2	1.3	1.3	0.3	0.9
0.1	>25	3.0	5.1	4.9	3.6	2.3	3.2	1.0	0.3	1.0
0.27	13.	0.9	0.9	1.0	0.3	1.4	3.2	0.2	2.9	1.0
0.5	7.	0.3	0.3	0.2	0.3	0.3	2.9	0.3	0.3	2.2

\# To reproduce empirically the induced drift of the Units 2 and 3 diffusers.

* HALF = half the discharge of the current up to 20 gpm in model.

** FULL = entire discharge of the current is routed to offshore suction (up to 35 gpm in model).

recorded in Unit 2 intake was 3.6% of ΔT_o corresponding to a temperature increment of 0.72°F. The resulting effect on the discharge from Unit 2 would therefore be a rise in the maximum recorded surface temperature of approximately 0.1°F corresponding to a dilution of 8:1.

The effect of this recirculation is seen to be greatest on Unit 1 itself since the plume from Unit 1 discharge would be drawn over the Unit 1 intake by the induced current. The peak observed temperature increment in the Unit 1 intake was of the order of 1.2°F corresponding to 6% of ΔT_o in the temperature of the intake water. The increase in temperature in the surface plume of Unit 1 would be less because of dilution. Detailed modeling of the Unit 1 discharge has shown that almost all of the dilution associated with Unit 1 discharge occurs close to the discharge point where an internal hydraulic jump can often be seen (Figure 4.3).

4.5 Relevance of Isotherms Determined in Laboratory Tests

The isotherms determined in the laboratory tests of the proposed diffusers are specified in percentages of the discharge temperature excess ΔT_o. The minimum isotherm given in the experimental results is 2.5% of ΔT_o which for a discharge temperature increment of 20°F corresponds to an isotherm of + 0.5°F surface temperature excess. Similarly, the 5% isotherm corresponds to 1.0°F and

Figure 4.3 Photograph showing dye pattern due to discharge of Unit 1 at ambient current = 0.27 knot prototype.

so on. The question that naturally arises is how these isotherms relate to temperatures actually measured in the ocean.

Ocean temperature records appropriate to the San Onofre site have been analyzed in some detail in Reference (5). The analysis shows that temporal variations in the ocean surface temperature of the order of 2°F can occur over a period of several minutes, and that the fluctuations over 5 days or so can be as high as 10°F (see Fig. 4.15). Infra-red radiometry and towed thermistor drogues disclose random spatial variations of at least 2°F. Figure 4.4 is a radiometric mapping of the surface plume from Unit 1 at San Onofre and it can be seen that the boundary of various temperature zones is far from clear. Figure 4.5 is a map of the isotherms at 3 meters depth for Palos Verdes (a region of the Pacific Coast NW from the San Onofre site). It can be seen that the natural variations in the near surface temperature are as large as 2.5°F in winter; summer fluctuations are generally even higher (see Figure 4.15). Thus the temperature contours determined in the laboratory will indicate increments over background only in an average sense. In fact it is quite possible that the temperature anomaly caused by the presence of the diffusers may be quite indistinguishable from naturally occurring anomalies such as shown in Figure 4.5.

In the summer months a natural temperature stratification occurs at the San Onofre site. Data (Figure 4.6) indicate

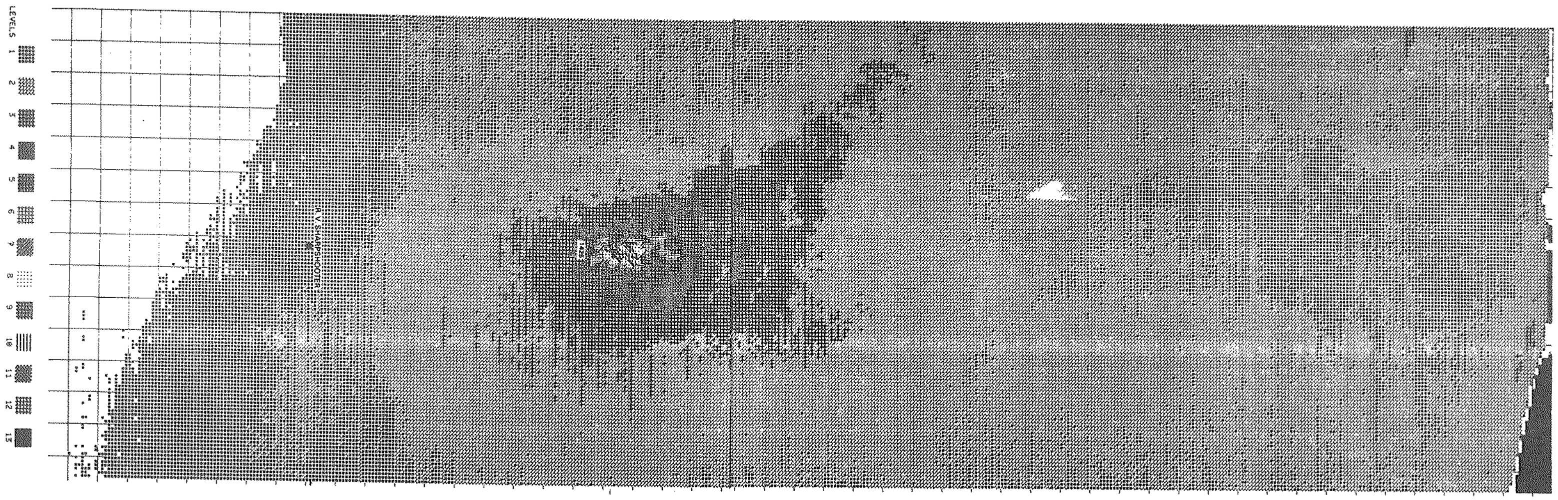


Figure 4.4 Radiometric map of the sea surface near San Onofre Unit 1 discharge. (Width approximately 1500 feet x 3500 feet) Ref. (10)

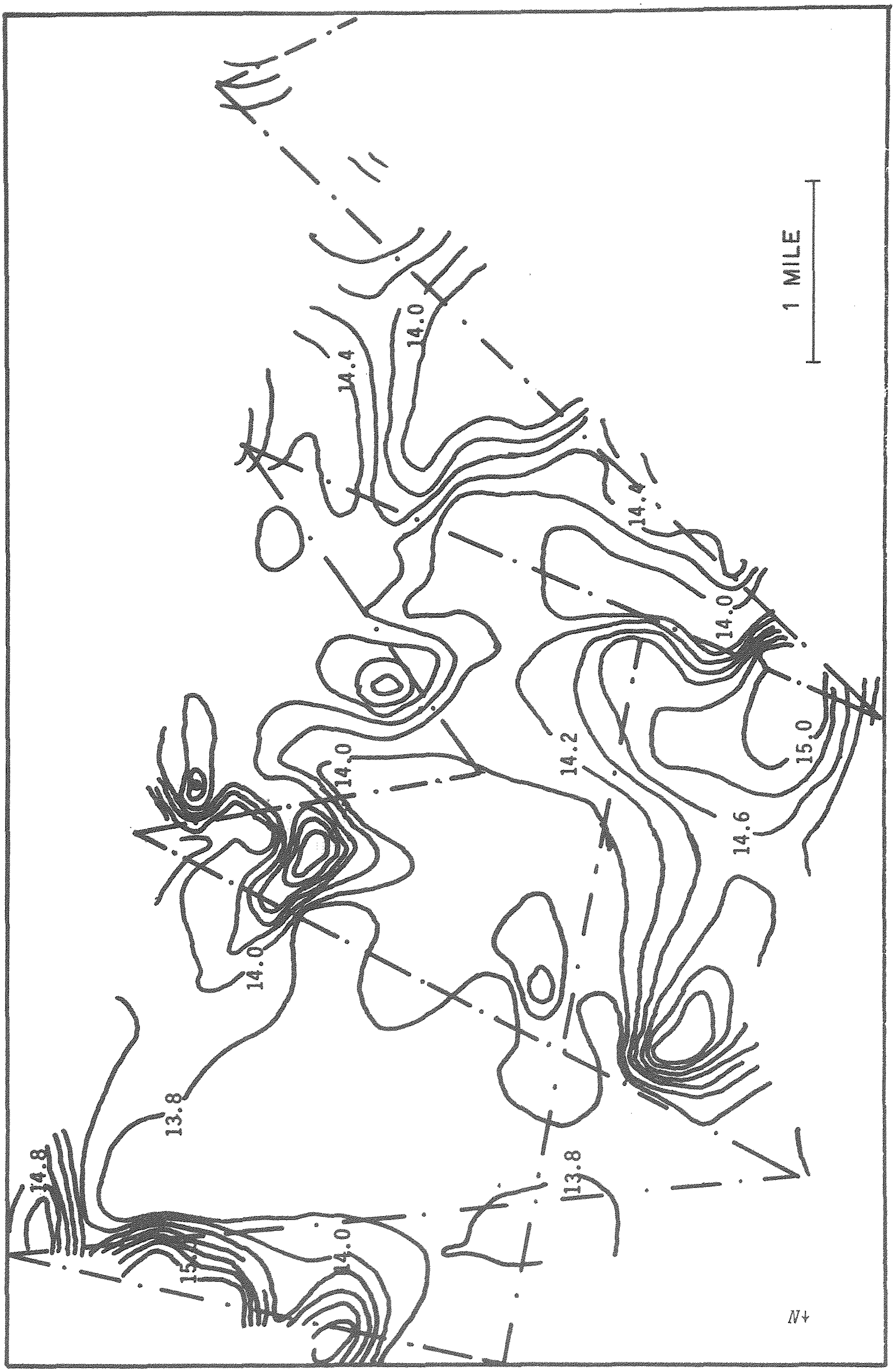


Figure 4.5 Three meter isotherms off Palos Verdes peninsula April 1972, Ref. (8).

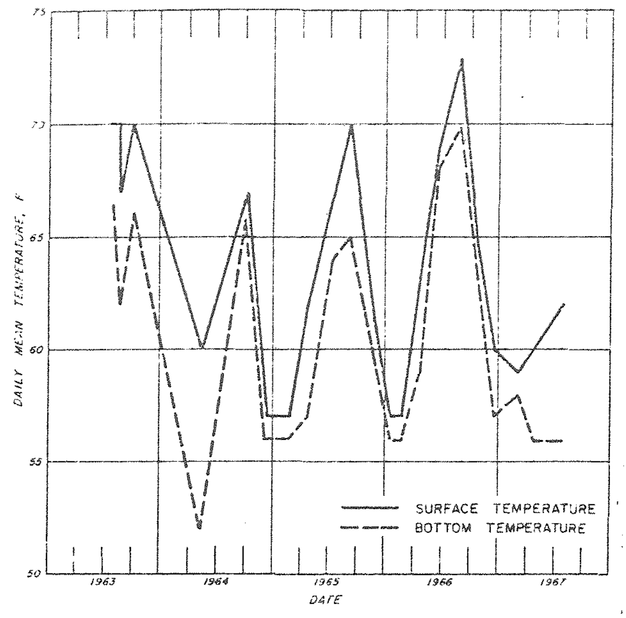


Figure 4.6 Daily mean natural temperature observed on survey days prior to Unit 1 operating (Ref. (4)).

that the difference between the surface and bottom temperatures may be as much as 8°F and is often more than 5°F. This means that since the colder bottom water will be entrained into the discharge plume by the diffuser jets, the net surface anomaly may in fact be a reduction in the surface temperature. It does seem highly likely that for a large percentage of the time in summer there will be little surface temperature manifestation of the presence of the outfall diffusers. The major effect of the heat addition may be a modification of the position of the naturally occurring thermocline. The net result is that the heat released will be in temporary storage as a modification of the thermocline and the heat transport will be by a gradual flushing of the area over a period of a few days (see Section 4.7).

In conclusion, it appears that only under exceptional conditions of ocean and atmospheric calmness will it be easy to detect the presence of the outfall diffusers beyond the $\Delta T = 2°F$ isotherm. The effect of the outfall diffuser beyond 1000 feet may be lost in the naturally occurring oceanic temperature fluctuations and only some kind of long term averaging process would be capable of determining the presence of the diffusion structures beyond the 1000 ft perimeter.

4.6 Interaction of Plume with the Ocean Current

When heated water is discharged to the ocean at San Onofre it is advected not only by its discharge momentum, but also by the existing ocean currents. It is, therefore, of importance to examine the nature of the ocean currents at the site.

A program of measurement of the ocean currents at San Onofre was conducted during 1972. Several recording current meters were positioned offshore of the generating station as shown in Figure 4.7. The data and some statistical analysis are presented in Reference (6). A further examination of the ocean current data has been made and the results presented in Reference (5).

The currents at San Onofre consist principally of three parts. First there is a mean drift. This is actually the manifestation of the effect of the interaction of the California current and Davidson current with the coastline, offshore islands, and bathymetry. Second, there is a tidal variation. Finally there is the remaining part with frequencies higher than the tides.

Figures 4.8 and 4.9 show example measured currents as they are broken into the low frequency (tides and lower) and high frequency contents for two representative current meter records. Figure 4.8 shows the data for Station F (see Figure 4.7) during the period 9/27/72 to 10/9/72, while Figure 4.9 shows the data for Station B during the period 2/1/72 to 2/7/72. On each graph, three curves are shown representing the actual data and the high and low frequency portions. Figures 4.10 and 4.11 show the corresponding progressive vector diagrams for the same two cases.

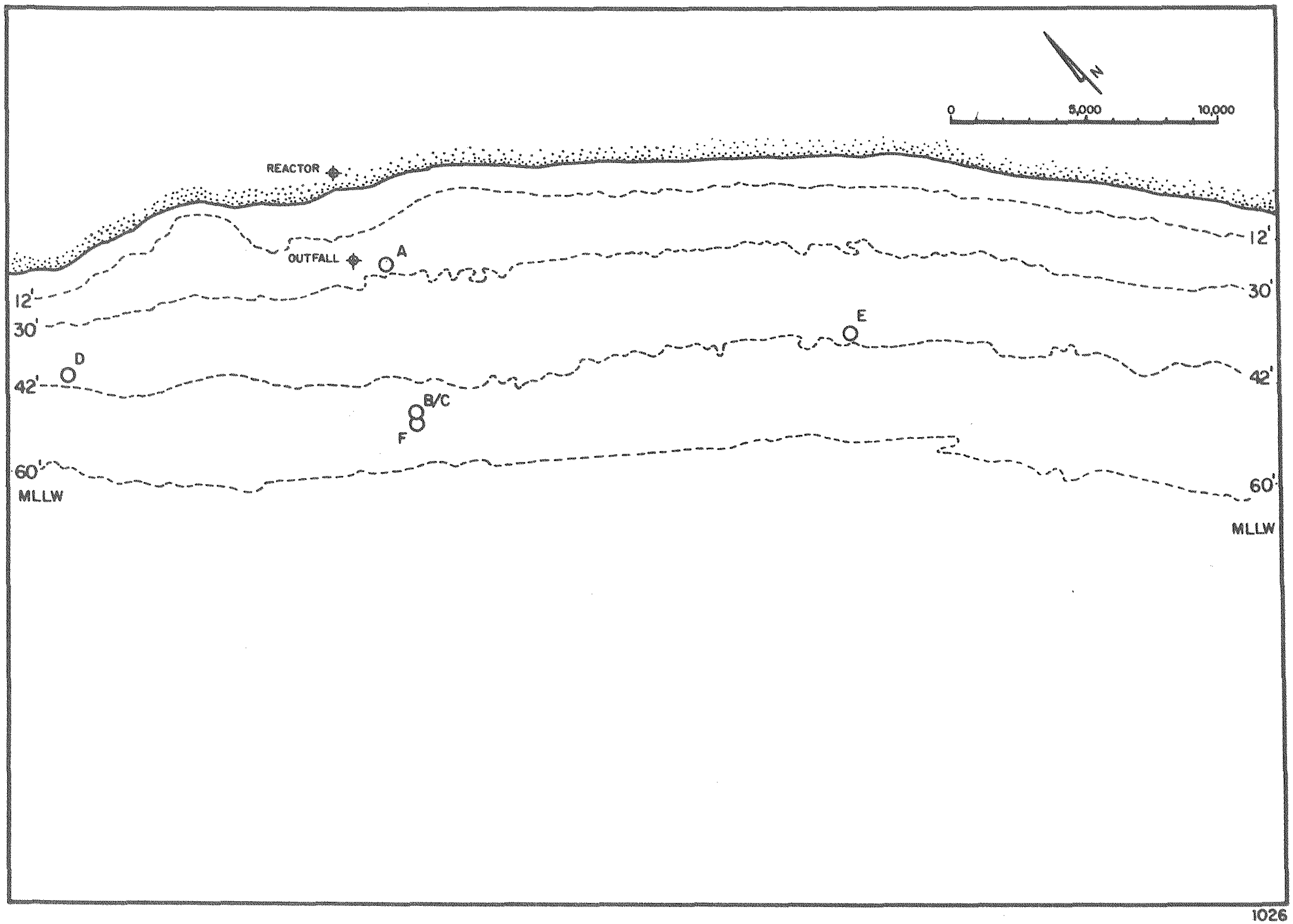
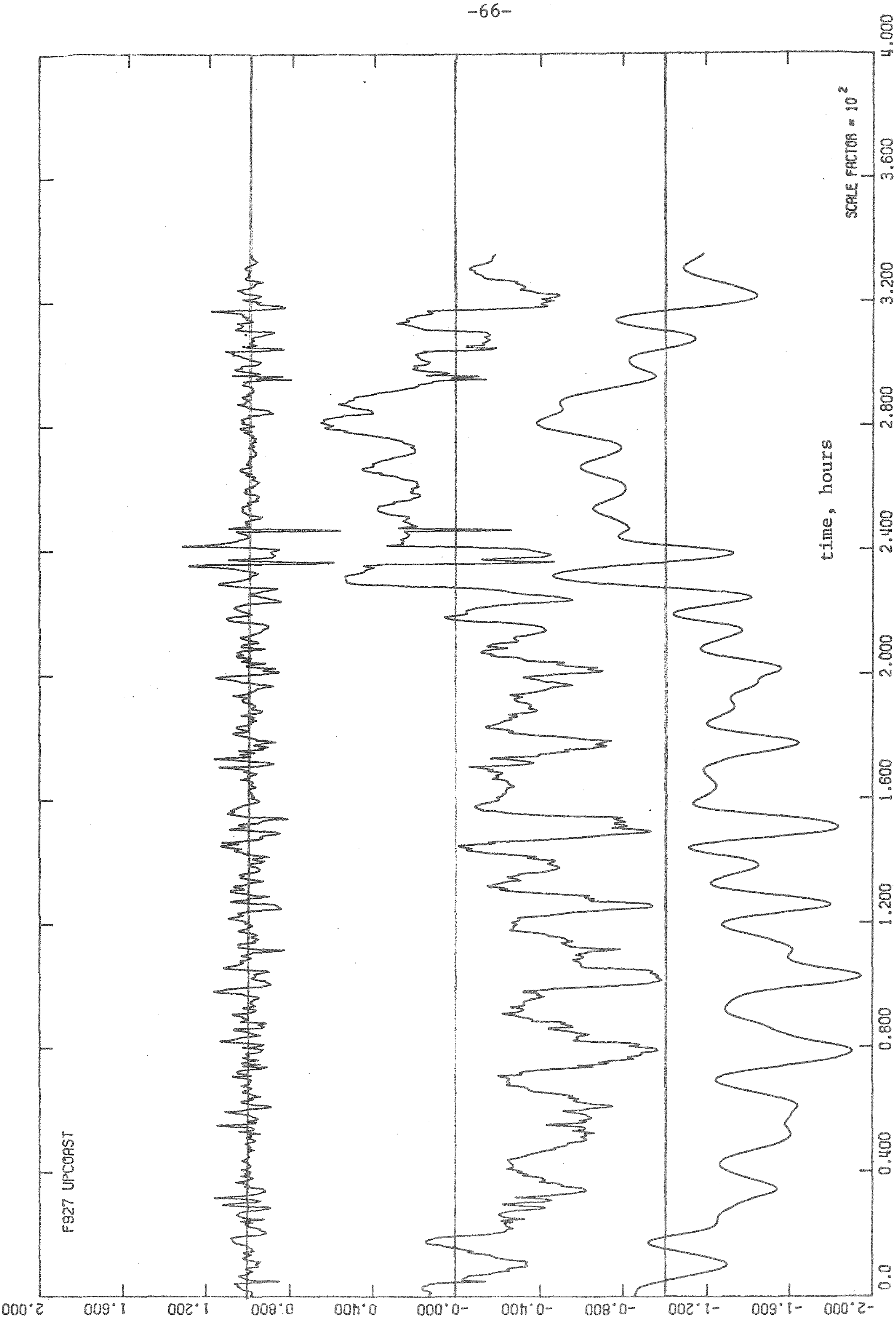


Figure 4.7 Current meter location chart. Bottom contours are depth in feet below mean lower low water (MLLW).



Current speed, knots
(successively displaced for clarity)

Figure 4.8a Current meter data for Station F during 9/27/72 to 10/9/72 (note vertical scale displaced for clarity)

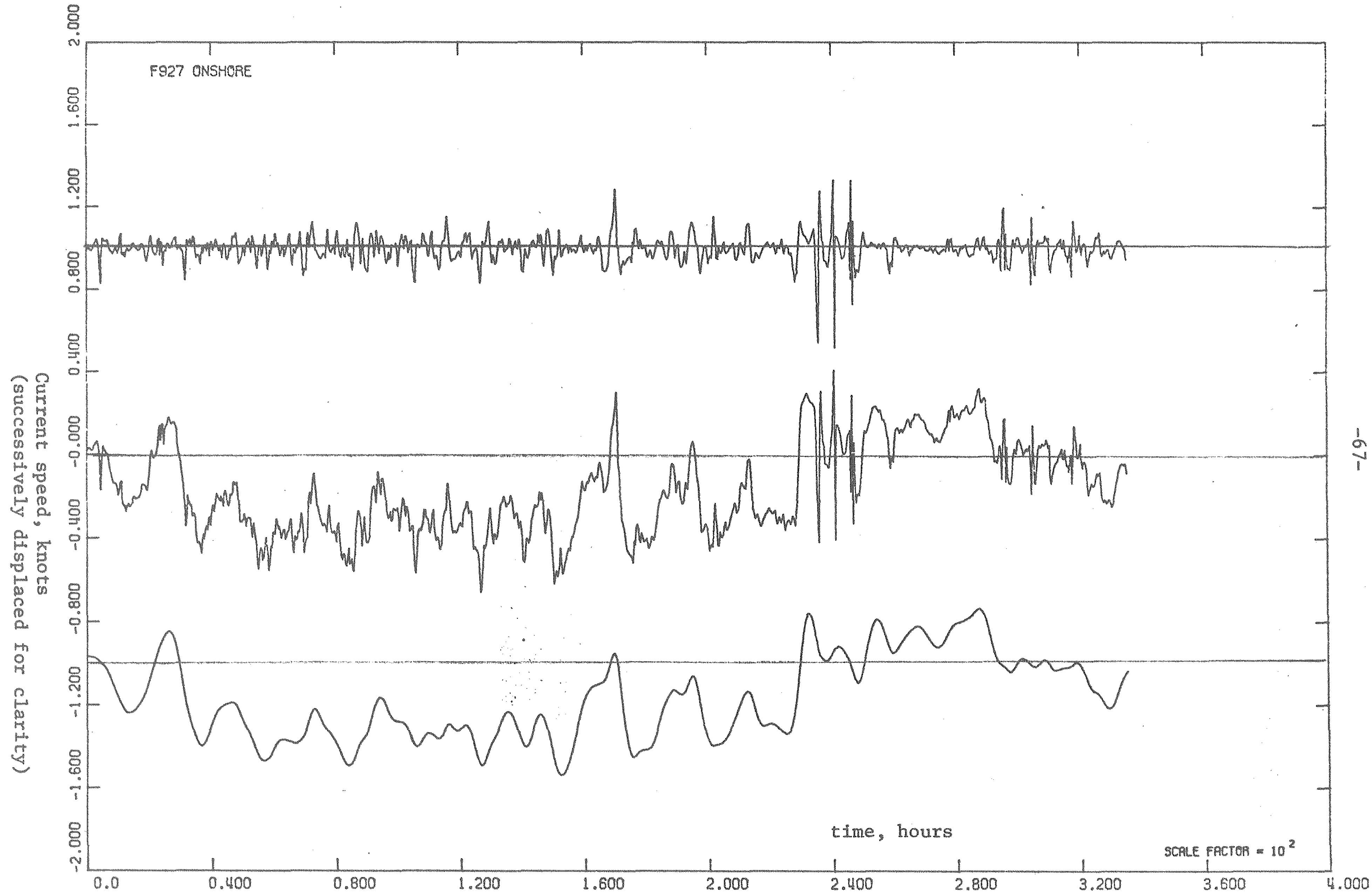


Figure 4.8b Current meter data for Station F during 9/27/72 to 10/9/72 (note vertical scale displaced for clarity)

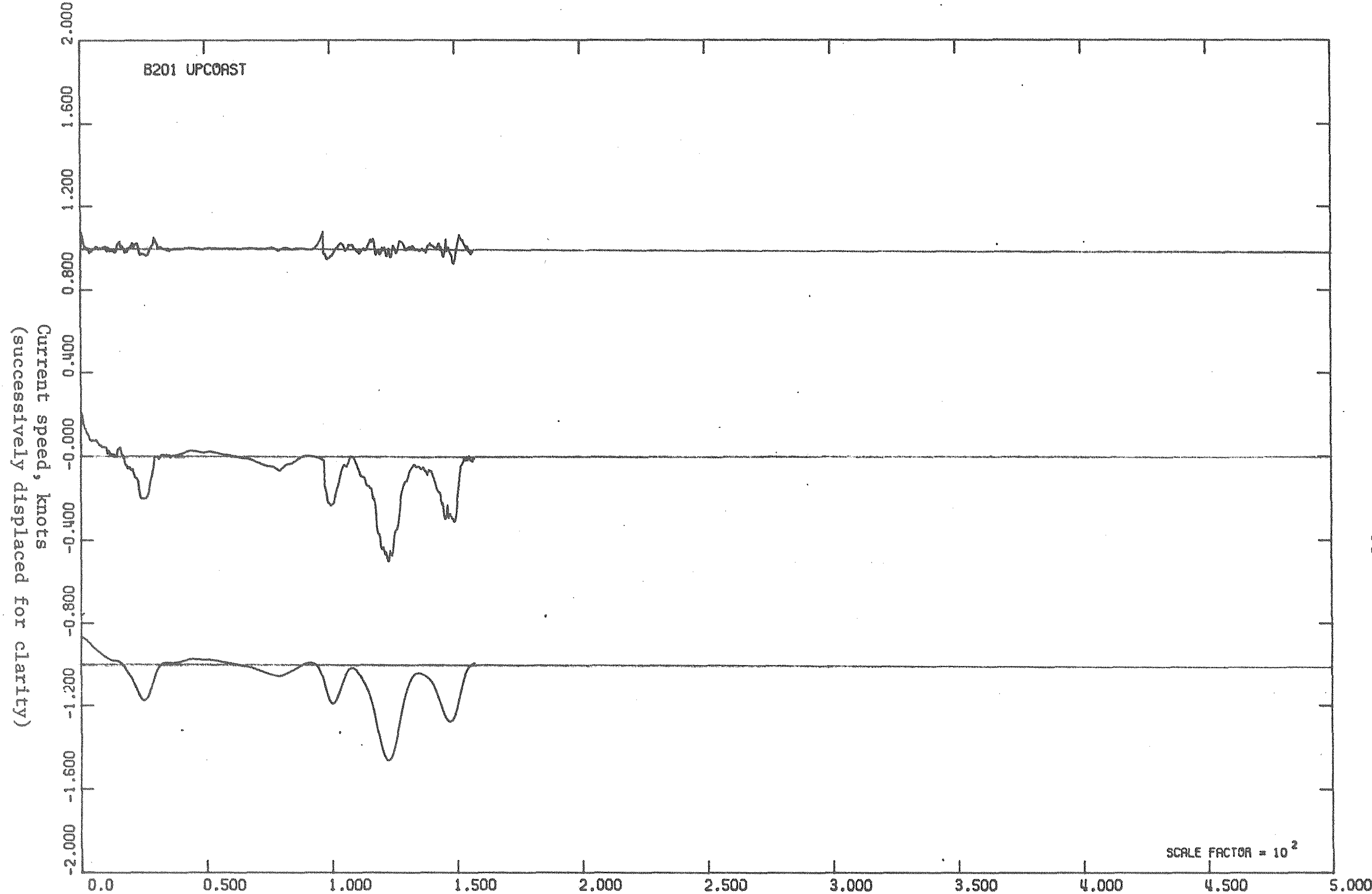


Figure 4.9a Current meter data for Station B during 2/1/72 to 2/7/72 (note vertical scale displaced for clarity)

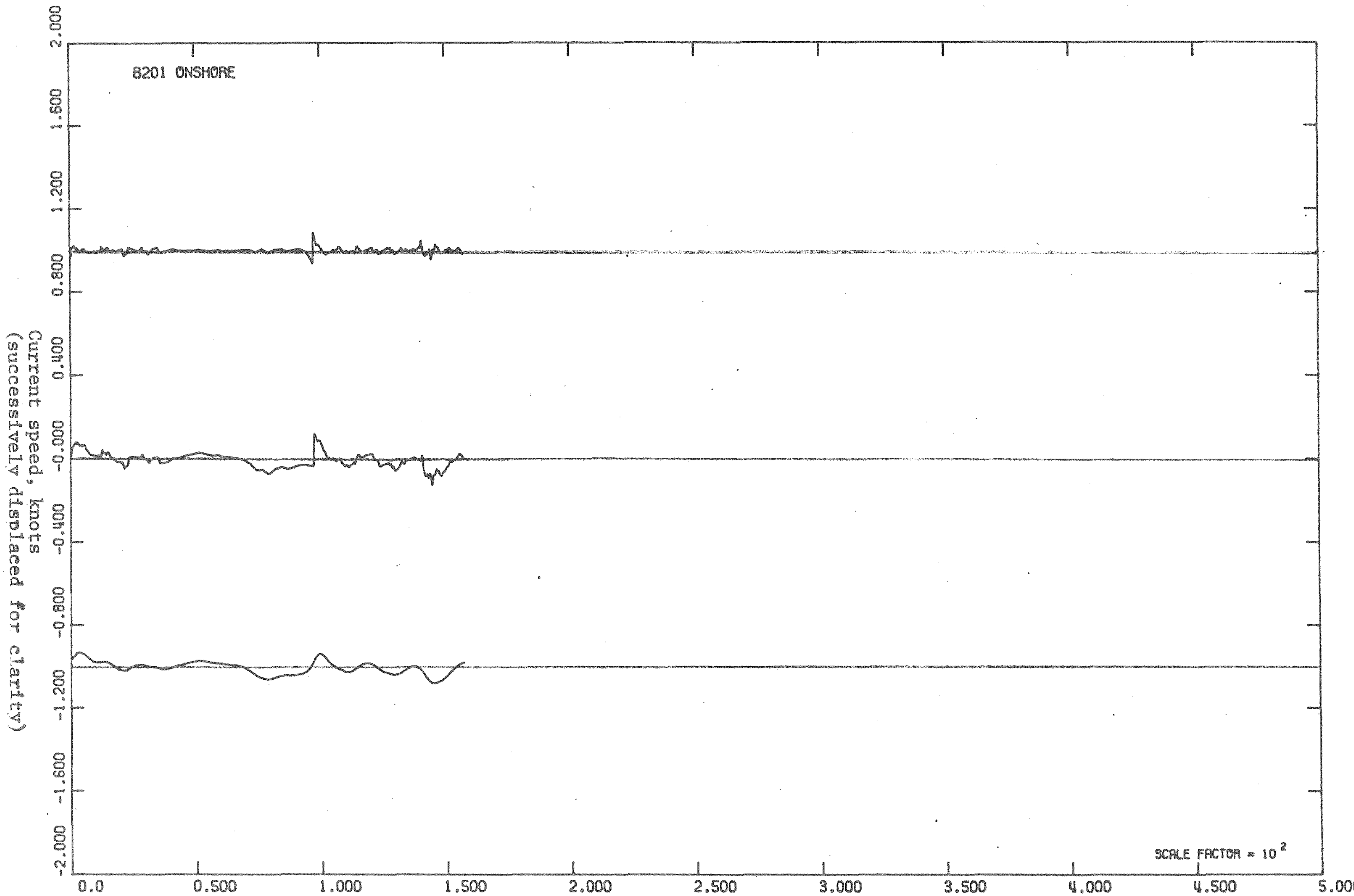


Figure 4.9b Current meter data for Station B during 2/1/72 to 2/7/72 (note vertical scale displaced for clarity)

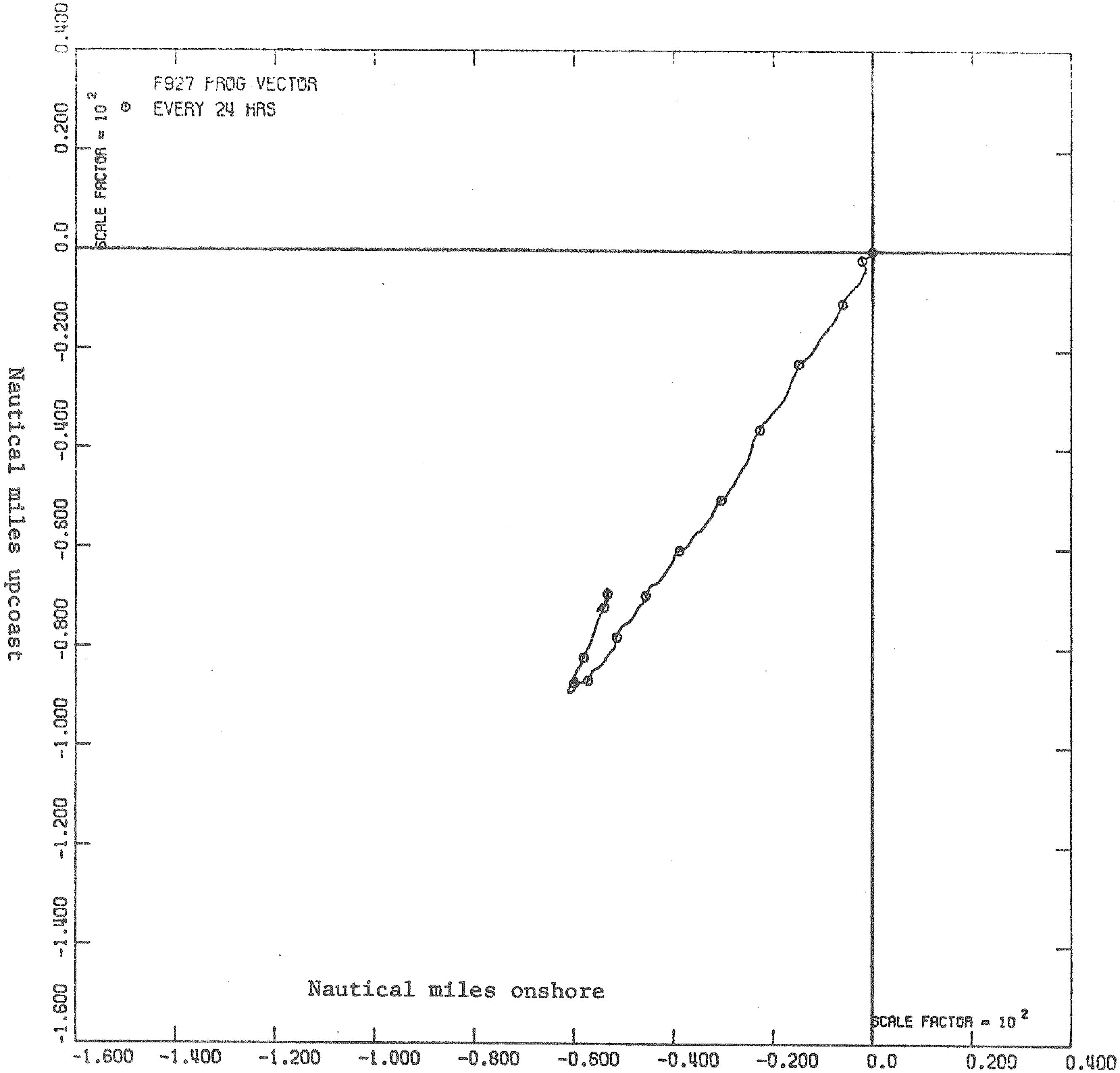


Figure 4.10 Progressive vector diagram for current at Station F during 9/27/72 to 10/9/72

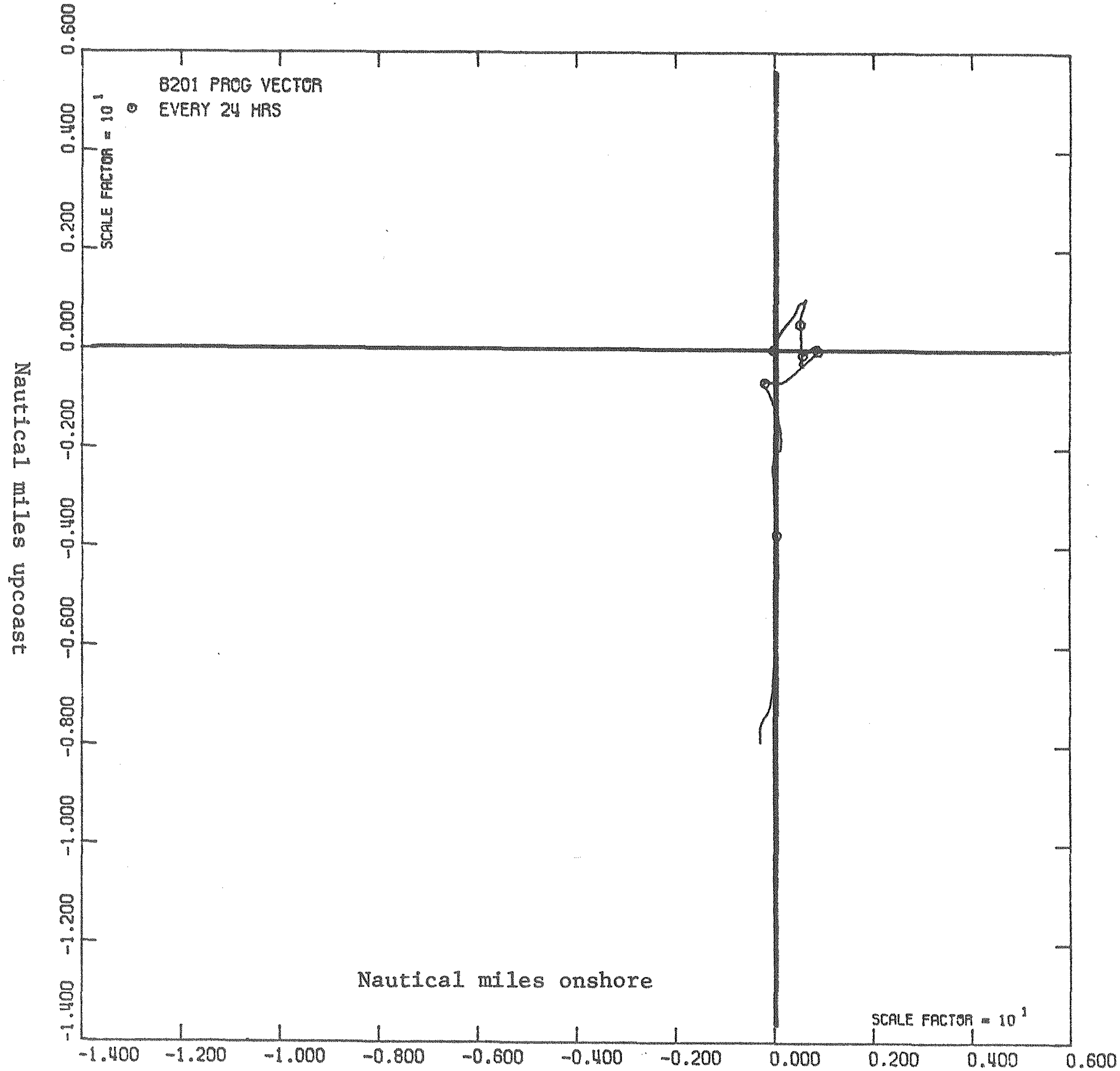


Figure 4.11 Progressive vector diagram for current at Station B during 2/1/72 to 2/7/72

These are chosen from among the many cases analyzed as representing typical summer conditions (F927) and a period of relatively weak currents (B201) which may occur during the winter. The complete data spans almost the entire year with gaps (for Stations B & F which are at the proposed diffuser site) in the months of January, March, April, July and December, primarily due to equipment malfunction.

In addition to the recording current meters, drogues were also released and tracked during the months of January and February 1972. They revealed that while there were periods of calm, the typical currents tend to run offshore and along the coast. They also do not reveal any eddy currents with zero net transport. Figures 4.12 and 4.13 show example drogue tracks. For the case shown in Figure 4.12, a progressive vector diagram based on current meter data obtained for Station B for the period 0000 2/9/72 to 2400 2/10/72, is shown in Figure 4.14 for purposes of comparison.

An attempt has also been made to determine the extent of spatial correlation between the currents measured at different stations. To this end, the current meter records for February 1972 for Stations D, E, and B were chosen and the corresponding measured velocities correlated versus each other. It was found that there was little correlation, particularly in the onshore component. However, simultaneous current measurements at several stations unaffected by Unit 1 discharge only existed for Feb. 1972 which may not be typical of conditions at the site.

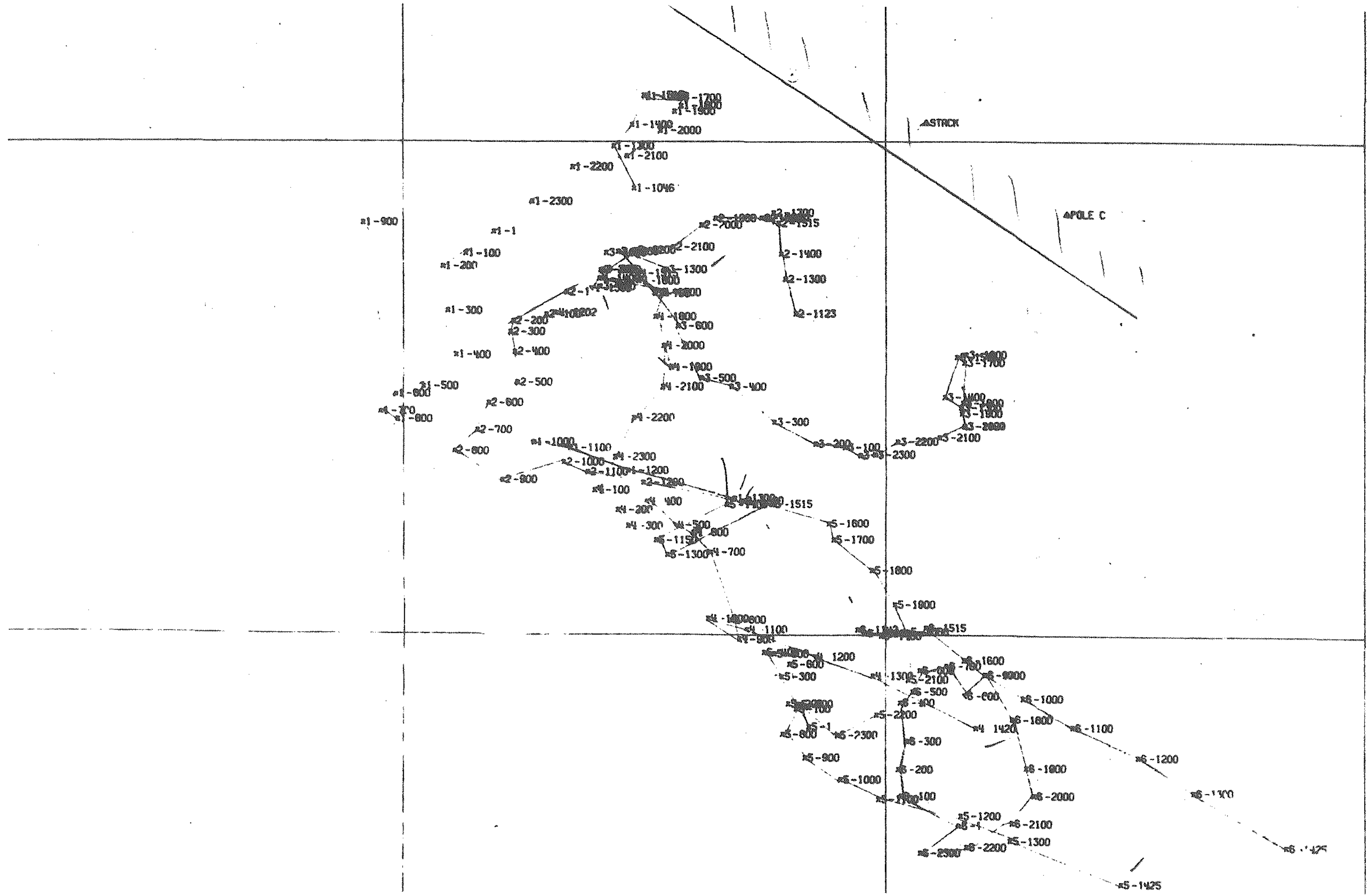


Figure 4.12 Drogue tracks measured during Feb. 9 and 10, 1972 off San Onofre.

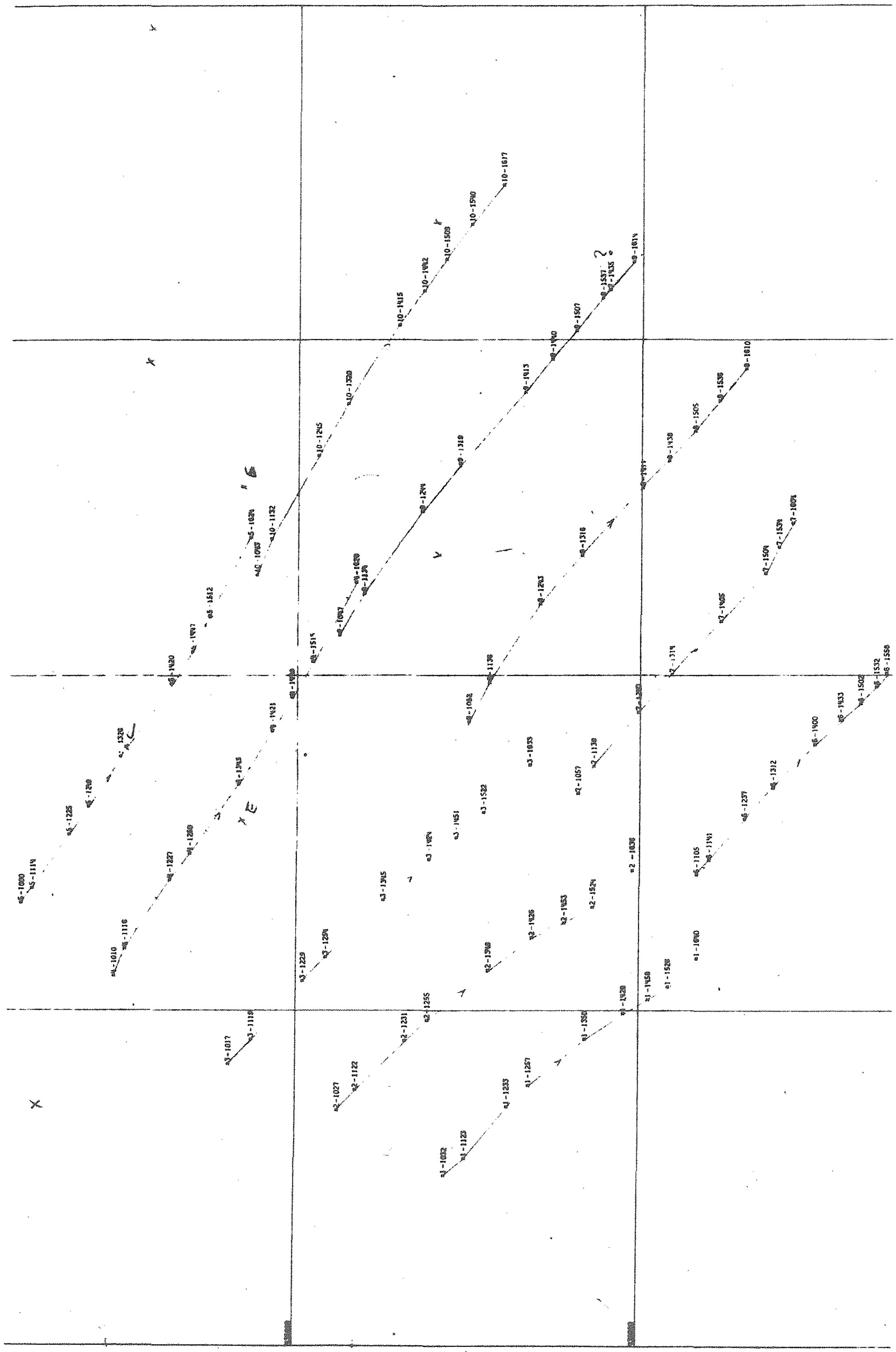


Figure 4.13 Drogue tracks measured during Jan. 1972 off San Onofre.

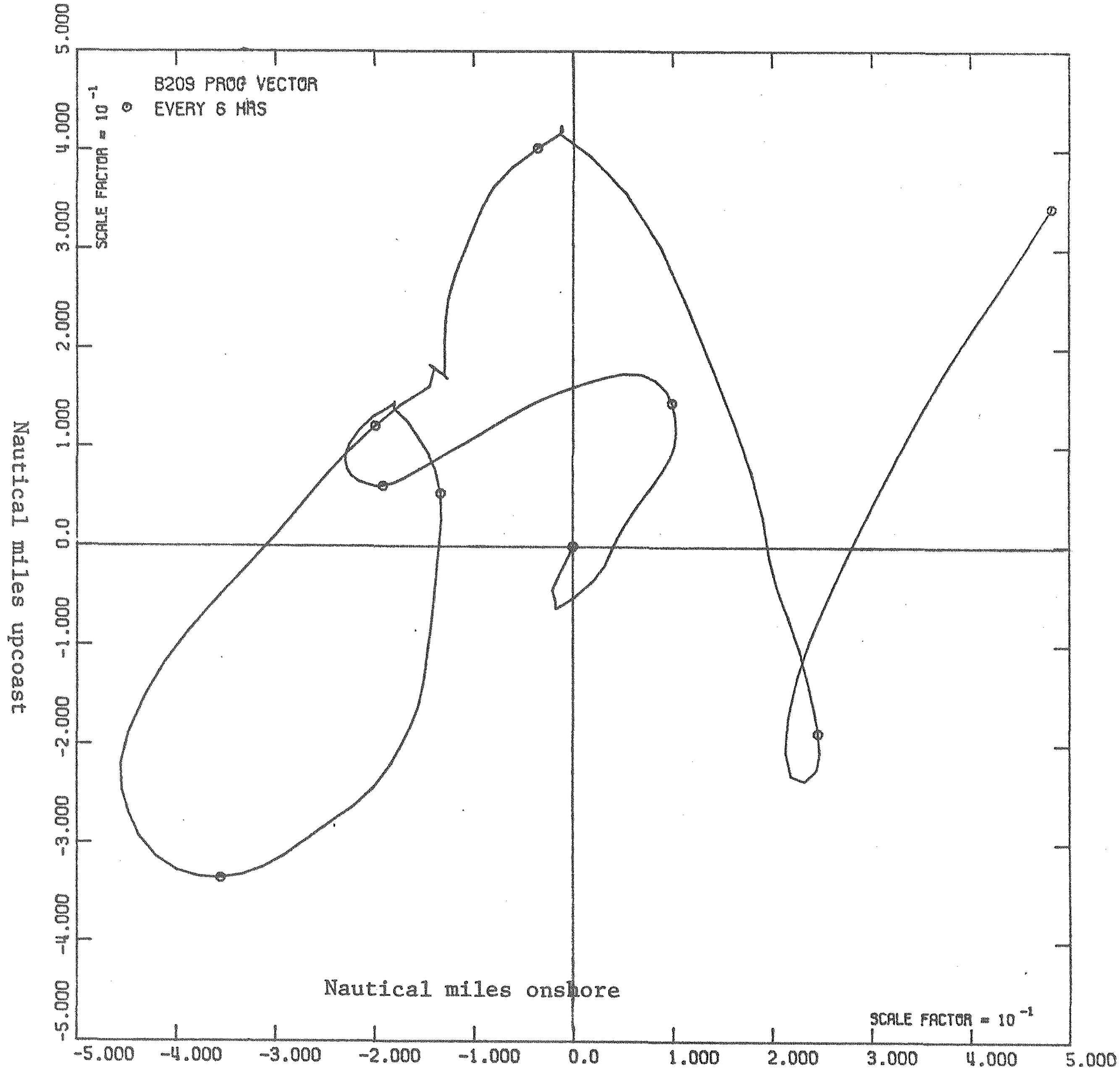


Figure 4.14 Progressive vector diagram for current at Station B during 2/9/72 through 2/10/72

From the analysis of the currents, it was concluded that the advective transport is primarily offshore and along the coast. There are periods during the winter when the currents are low. These low currents may persist for a period on the order of a few days. Onshore current components in the Eulerian sense do exist and persist at times at the measuring stations; however, simultaneous drogue data indicate that the Lagrangian transport is still principally alongshore and offshore.

It should be cautioned that the use of progressive vector diagrams to indicate the net mass transport may lead to serious errors in the nearshore zone where the currents tend to be highly variable. Progressive vectors are only meaningful over horizontal distances less than the positive correlation distance. At San Onofre, at least in winter this is less than a few thousand feet.

The importance of current meter data is to provide an understanding of the motions which occur in the ocean. The existing data analyzed is deficient in principally two ways. First, there is no multistation simultaneous data other than in February. Thus the spatial correlation is largely unknown. Second, the months of December, January, March and April were missed in the data collection program for station B or F near the diffuser location. Moreover, it was shown in Ref. (5) that the flushing currents are possibly weak in the January-February period in the Southern California Bight, thus making further local current information during these periods essential.

In the nearshore areas off Southern California where the currents are complex, it will be difficult to obtain estimates of net flushing from current meter data unless a large number of meters are deployed over a long time. However, an alternate method is available due to the fact that the mean heat transfer is almost always into the water throughout the year. Temperature measurements in the water, along with meteorological measurements and the application of heat budgets can provide the necessary information with regard to coastal flushing. This was discussed in detail in Ref. (5).

The laboratory model tests discussed in Section 3 included experiments for a variety of ambient currents varying from stagnant to a prototype value of 0.6 knots both for steady currents and reversing currents. Special currents chosen from the current meter records were also tested. The primary result obtained was that the maximum surface temperature excess observed beyond the immediate vicinity of the discharge structure under all the conditions tested amounted to less than 12.5% of ΔT_o or 2.5°F.

It should be noted that the ambient current in the laboratory is always longshore. Neither onshore nor offshore currents were tested. Since there are periods when onshore currents occur, it is of importance to estimate the effect this may have on the heat dispersion. As noted above, even though there are periods of persistent onshore current component in the Eulerian sense, the Lagrangian transport is still primarily longshore and offshore. The effect of the onshore flow may then be expected to be a retardation of the offshore drift generated by the diffuser discharge. The onshore current component observed at the site, when it occurs, is rarely more than 0.25 knot and is typically less than 0.1 knot. The offshore drift generated by the discharge momentum is of the same order of magnitude. As an estimate, the heat dispersion in the event the offshore discharge momentum is completely cancelled by the existing onshore momentum will be estimated. The research results of Jirka and Harleman, 1973 (Ref. 7) will be used. They investigated the case of multiport thermal discharges with no offshore momentum in a stagnant basin when the effects of reentrainment were included. Using their method the estimated surface temperature excess for the San Onofre diffuser is 7 to 12% of ΔT_o or 1.4 to 2.4°F for discharge depths of 50 to 30 ft respectively. In this case, the discharge momentum has the effect of offsetting the onshore momentum in the ambient currents and still entraining deeper water for dilution.

In summary, the currents at San Onofre are predominantly longshore as is borne out by both the recording current meter data and the drogue data. At times, an onshore component does exist in the current meter data but is generally of low magnitude. The discharge momentum has the effect of offsetting this shoreward momentum during these periods. However, laboratory tests did not include testing the performance of the diffusers under these conditions. The results of Jirka and Harleman (Ref. 7) indicate that the surface temperature under adverse current conditions may be as high as 2.4°F. This may be compared with the laboratory measured value of 1.9°F ± 0.4°F. Thus, an estimate of the effect of adverse current conditions on the performance of the Units 2 and 3 diffusers is +0.5°F in the average surface temperature excess.

4.7 Ultimate Heat Loss

It is obvious that unless some mechanism exists to remove the heat introduced to the ocean by the diffusers, then the ocean in the neighborhood of the diffusers must undergo a continuous increase in temperature. The mechanisms by which heat removal can and will occur have been studied in detail in Reference (5). The results of that study will be summarized here since they are of importance to the assessment of the prototype diffuser operation. The results of this present study of the projected diffuser operation implicitly assume that a mechanism for heat removal does exist.

There are two mechanisms by which heat can be removed from the ocean at the San Onofre site. It can be advected away by the ocean currents or passed to the atmosphere. Which of these two mechanisms is the predominant one will vary from day to day in response to changes in the meteorological and oceanographic variables.

The analysis of ocean and atmospheric data records in Reference (5) indicates that if diurnal effects are ignored, then throughout the year there is almost always a net transfer of heat from the atmosphere to the ocean. This results from the fact that there is always a net absorption of radiation by the ocean and the evaporative and conductive losses of heat from the ocean are insufficient to compensate for the net absorbed radiation. Since there is a net transfer of heat to the ocean (the rate averaging about 7 watts/ft^2), and yet the ocean in the Southern California Bight is not continuously increasing in temperature, the heat must be advected out of the area by the ocean currents on an annual basis.

Daily temperature records available for the ocean area in the neighborhood of the San Onofre site show intense temperature fluctuations over periods of 5-7 days with a seasonal variation superimposed (Figure 4.15). There is no indication that there is a region of anomalously high temperature in the San Onofre region. Hence it must be concluded that the overall advective transport in that region of the coast is no different from other nearby coastal areas. If there were a local flushing anomaly this would be reflected in higher mean temperatures than those occurring nearby. The daily temperature data revealed (Ref. (5)) that there is a period of winter warming of the whole coastal region (from Newport to La Jolla). This midwinter warming (Jan.-Feb.) could be due to low overall coastal flushing. The current data from the San Onofre site, however, indicate that local currents do exist during this period although they are weak at times (see Figures 4.12 and 4.13). It should be noted that even if a period of relatively low flushing does exist during January and February, this does not imply that there is no mechanism for dissipation of the temperature excess of the thermal discharge at San Onofre. Although the net overall heat transfer is most probably from the atmosphere to the ocean during this period, the temperature excess in the discharge plume will still decrease because of the differential transfer between the ocean and the plume. When the overall transfer is to the ocean the transfer coefficient is in general lower than when the overall transfer is in the opposite direction.

A very conservative estimate of the size of the plume that would be necessary to dissipate the 5600 MW of power rejected from Units 1, 2 and 3 during an extended period of zero flushing can be made as follows. Suppose that the atmospheric transfer coefficient were only 80 BTU/ft.^{2} day °F., then the area required to reject 5600 MW at a mean 2°F temperature increment would have a diameter of about 11 miles. Such an estimate represents about the largest possible size of plume that could ever possibly form since it is based on the assumptions of minimum atmospheric transfer, and maximum anticipated dilution by the diffuser. It should be recognized that such a calculation does not imply that a 2°F isotherm will even necessarily be as large as 10 - 11 miles in diameter. The actual distribution of isotherms, if such a large plume would ever form, is extremely difficult to compute since the thickness of the plume is involved. The calculation merely provides <u>an order of magnitude</u> estimate of the largest-size plume that would form under conditions of sustained minimum atmospheric transfer and zero coastal flushing. The probability of such a simultaneous occurrence is in all likelihood extremely low. The temperature excess would exceed this increment only through recirculation of the discharge through the cooling water intake, or re-entrainment of the discharge plume. These phenomena are prevented from occurring by the density stratification induced by the temperature excess as is shown in Section 4.4 above.

Thus, even in the possible, but unlikely event, of prolonged lack of ocean flushing, an effective means of dissipation of the temperature excess exists to limit the area of influence of the San Onofre discharge to an area less than 10 - 11 miles in diameter. Furthermore, even under such adverse conditions, the thermal discharge regulations would be satisfied. Under normal conditions, the area of influence would be much smaller, as indicated in Ref. (1) (see e.g. Figure 3.11, p. 27).

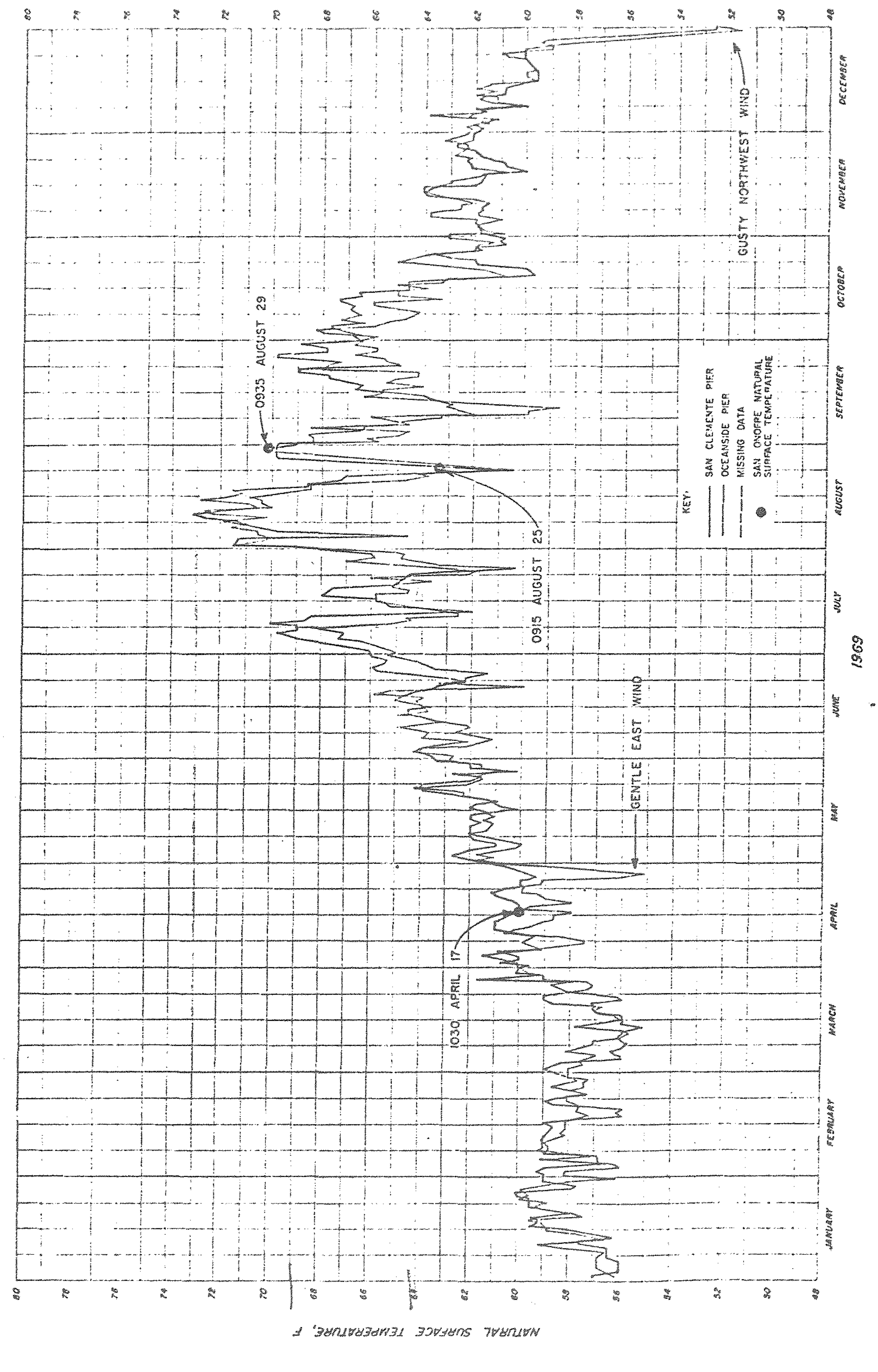


Figure 4.15 Daily mean natural surface temperature
San Clemente and Oceanside 1969

5. Summary and Conclusions

Laboratory studies of a hydraulic model of the proposed San Onofre Nuclear Power Plant thermal outfall diffusers (Ref. (1)) coupled with an analysis of field data on ocean currents, temperatures, and heat transfer (Ref. (5)) have lead to the following results:

(1) Laboratory tests of hydraulic models (for San Onofre Units 2 and 3 diffusers), which included sensitivity analysis both for design variables and modeling procedures, have lead to a best estimate of the maximum surface temperature excess (beyond 1000 ft of the discharge) of 1.9°F±0.4°F.

(2) An assessment of the effects of field conditions not completely or properly represented in the laboratory tests lead to the following estimates:

(i) Unit 1 discharge could have two possible extreme effects. It could be entrained into the Unit 3 discharge plume becoming part of the diluting water for Unit 3 or it could float over the Unit 3 discharge plume. In the first case the increase in the surface temperature excess induced would be less than 1°F. In the second case the temperature increment in the region between Units 1 and 3 would be governed primarily by the Unit 1 discharge.

(ii) The net effect of the offshore momentum induced by the diffuser will be to induce an offshore current of approximately 0.2 knot (0.3 ft/sec).

(iii) Reentrainment of the discharged effluent into the discharge plume is believed to be a very unlikely event due to the offshore momentum imparted to the discharge. Even if the offshore drift is temporarily impeded by an onshore current, the thermal stratification will tend to inhibit entrainment of surface warm water into the plume. Almost all dilution will occur from the deeper colder water in the neighborhood of the diffuser jets.

(iv) Recirculation of Unit 1 discharge into Units 1, 2, and 3 intakes will occur to a minimal degree. The largest estimated effect on Unit 3 discharge will be an increase of 3.6 % of ΔT_o in the temperature of the intake water. The effect on the discharge plume, assuming 8:1 dilution, will be less than 0.5% of ΔT_o or 0.1°F.

(v) Analysis of the ocean temperature data indicates that the fluctuations in the natural temperature may be of the order of ±2°F and ±1°F in the summer and winter months respectively. Definition of natural temperature, therefore, can only be made statistically and only to the same degree of accuracy. Moreover, prototype temperature excess isotherms of less than 2°F will be buried in the background noise except for brief periods of unusual calm. In the summertime it is likely that a manifestation of the diffusers may be a slight reduction in the mean local surface temperature rather than an excess.

(vi) Analysis of the ocean current data indicates that the predominant direction of the ocean currents is parallel to shore with a mean down coast (southerly) transport. Although current meter data indicate brief periods of onshore transport, drogue studies during these periods indicate no net onshore transport. Magnitudes of such local onshore current velocities are typically less than 0.25 knots. The experiments by Jirka and Harleman (Ref. 7) with models of no net offshore transport indicate maximum temperature excesses of about 12% of ΔT_o indicating the maximum additional allowance for adverse current conditions should be +0.5°F.

(vii) Estimates of surface heat transfer rates at the San Onofre site indicate that there is almost always a net monthly transfer of heat from the atmosphere to the ocean for all seasons of the year. This fact, combined with ocean temperature data, indicates a possible period of overall weak coastal flushing in the South Coastal area in January and February. However, local current data from San Onofre indicate that local currents still persist during this period but may be weak for periods of up to several days.

(viii) The effect of a period of weak overall flushing would be to place greater emphasis on atmospheric dissipation of the heat rejected from the San Onofre power plant. Although there may be no <u>net</u> heat transfer to the atmosphere, the discharge plume will still decrease in temperature relative to the natural ocean. It is conservatively estimated that in the event of a sustained period of no flushing and minimum atmospheric transfer, the largest area ever likely to be covered with a mean 2°F temperature increment due to the discharge plume will have a diameter of the order of 11 miles. The probability of such an occurrence is regarded as very small.

(3) An estimate of the worst maximum temperature excess to be anticipated from the operation of the San Onofre outfall diffusers can be made both excluding and including the effect of Unit 1.

(i) <u>Excluding Unit 1</u>

Laboratory study most probable estimate	1.9°F ± 0.4°F
Allowance for adverse current	0.5°F
	2.4°F ± 0.4°F

(ii) Including Unit 1

EITHER

Laboratory study best estimate	1.9°F ± 0.4°F
Allowance for adverse currents	0.5°F
Allowance for portion of Unit 1 discharge recirculated through Unit 3	0.1°F
Allowance for entrainment of Unit 1 discharge by Unit 3 discharge (50% of 1°F)	0.5°F
	3.0°F ± 0.4°F

OR

If Unit 1 discharge is not entrained but floats on Unit 3's diluted discharge then the maximum temperature excess will be the larger of the two individually. The maximum surface temperature excess in this region may exceed 4°F on occasion .

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